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**SNAME PANEL SP-3  
Surface Preparation and Coatings  
REPRINT  
U.S. DEPARTMENT OF TRANSPORTATION  
Maritime Administration  
  
in cooperation with  
National Steel and Shipbuilding Company  
California**

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE <b>1971</b>		2. REPORT TYPE <b>N/A</b>		3. DATES COVERED <b>-</b>	
4. TITLE AND SUBTITLE <b>Prefailure Evaluation Techniques for Marine Coatings</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Naval Surface Warfare Center CD Code 2230- Design Integration Tools Building 192, Room 138 9500 MacArthur Blvd Bethesda, MD 20817-5000</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release, distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>SAR</b>	18. NUMBER OF PAGES <b>284</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

# **PREFAILURE EVALUATION TECHNIQUES FOR MARINE COATINGS**



**U. S. DEPARTMENT OF COMMERCE  
MARITIME ADMINISTRATION**

**IN COOPERATION WITH**

**GENERAL DYNAMICS**

**QUINCY SUBMARINE DIVISION**

54361  
70360

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**PREFAILURE EVALUATION TECHNIQUES  
FOR MARINE COATINGS**

**FOREWORD**



PREFAILURE EVALUATION TECHNIQUES  
FOR MARINE COATINGS

FOREWORD

This report is the end product of one of the many research projects being performed under the National Shipbuilding Research Program. The program is a cooperative, cost shared, effort between the Maritime Administration's Office of Advanced Ship Development and the shipbuilding industry. The objective, as conceived by the Ship Production Committee of the Society of Naval Architects and Marine Engineers, "emphasizes improved productivity and therefore reduced shipbuilding costs to meet the lower Construction Differential Subsidy rate goals of the Merchant Marine Act of 1970.

The studies have been undertaken with this goal in mind and have followed closely the project outline SP-2-10 as published by the SNAME Ship Production Committee.

We wish to acknowledge the assistance of Mr. David T. Bloodgood of Bethlehem Sparrow's Point Shipyard in the evaluation of proposals which resulted in the selection of Battelle Columbus Laboratories to do the preponderance of the research work. The full report is in Section A. The research was done under the direction of Mr. L. J. Nowacki and Mr. Richard Dick.

The award to New York University for the Establishment of Hand Operated Methods for Paint Thickness Measurements over Grit Blasted Surfaces was made as the result of an unsolicited proposal. The report of this study which was directed by Dr. Max Kronsteinis in Section B.

Mr. Wilder Moffatt, General Dynamics Quincy Shipbuilding Division, was the Program Manager, assisted by Mr. George A. Rudlowski, Coating Chemist.

Special acknowledgement-is due also to the following for their constructive criticism of the manual in its draft form:

Avondale Shipyards, Inc.  
Bath Iron Works Corporation  
Battelle Columbus Laboratories  
Bethlehem Steel Corporation  
Society of Naval Architects and Marine Engineers  
Todd Shipyards Corporation - Galveston Division  
Todd Shipyards Corporation - Seattle Division



**PREFAILURE EVALUATION TECHNIQUES  
FOR MARINE COATINGS**

**EXECUTIVE SUMMARY**

## PREFAILURE EVALUATION    TECHNIQUES FOR MARINE    COATINGS

### EXECUTIVE    SUMMARY

Two studies were made as noted in the Foreword on page 1, and the complete reports follow. The number of tests available to control quality of product, surface preparation, application and cure are too numerous to use in their entirety in shipyard painting. Further, there are today very few tests which can determine the probability of failure of a coating system with any degree of reliability after application. The success of a coating system is dependent on many things from surface condition to weather at time of application. The only assurance of the quality of a coating system comes from monitoring and controlling the surface preparation, paint quality and application. A few post application tests can be made to obtain limited assurance that the coating system will perform satisfactorily. The probable minimum practical tests and controls are:

#### Surface Preparation (Abrasive blasting)

Establish requirement based on standards such as the Steel Structures Painting Council, the Swedish Surface Preparation Standards or the Society of Naval Architects and Marine Engineers Bulletin 4-9, Abrasive Blasting Guide for cleanliness and profile.

Establish process to obtain specified standards including abrasive mix.

Test surface profile at intervals

Make sieve analysis of abrasive at intervals

Observe surface prior to coating to identify deterioration since preparation:

Cleanliness  
Rusting  
Moisture

#### Paint

Establish specifications (or obtain them from vendor) and make sufficient tests to insure that product is within specifications, such as:

Condition in can, viscosity, weight per gallon, non-volatile content, drying time, flash point, fineness of grind, color, gloss, sagging, levelling, specific gravity, application characteristics.

### Application

Establish standards and limits and test for compliance.

Temperature, humidity, thinning, wet film thickness, ventilation, equipment condition, time between coats, application techniques.

### Post Application

Establish standards and limits and test the applicable attributes for compliance.

Dry film thickness (each coat)  
Adhesion  
Abrasion  
Impact  
Continuity  
Color  
Gloss

While the above list is considered to be a reasonable minimum, there are many more tests and controls included in the manual which might be used to enhance the probability of success. We leave this to the individual shipyard to determine the extent of their program.

Certain of the tests can be used best as controls which are performed by the operators themselves. Examples of these are:

Surface preparation can be checked by the blaster against Kean-Tater samples.

Wet film thickness can be checked by the painter using a simple durable wet film thickness gage.

Humidity is one of the worst enemies of good adhesion of most paints. The tests are simple but are not considered to be practical of accomplishment at the workman level. It is possible that humidity checks could be made at the foreman level but certainly at the quality control level to determine whether painting should proceed or not.

The remainder of the checks listed above should be made either by quality control or laboratory personnel.

Although many people would like to see a "little black box" which can be held against a coated surface that will "tell all", such a device is not available nor is it expected to be available at any time in the near future. Although after application tests can help to discover errors which can be reworked to prevent premature failure, the most cost effective method is to apply properly conceived and controlled specifications, products and processes throughout the construction period.

Full discourse of the study findings and recommendations are included in the main body of the report.

## Coatings Department Personnel

Qualified technical personnel should direct the coatings Department. Coatings have graduated from an art to a science and qualified coatings personnel are required to get full utilization from today's sophisticated coatings.

## Education Programs

Training programs are desirable to develop satisfactory operators and to provide motivation. They should include coatings technology relatable to the individual's involvement in the coating program.

## Summary

From the shipyard's standpoint the best way to obtain a quality coating system is still to:

1. Carefully specify what is required.
2. Do as much preparation and painting as possible indoors.
3. Carry out good application processes.
4. Use practical product and in process checks and controls.
5. Avoid preparation and painting when weather conditions are beyond the limits for success.

## Potential New Tests

One new approach to testing of adhesion that shows some promise was developed during this project. This consists of applying a high pressure to a coated surface for a period of time and then suddenly releasing the pressure. Further investigation would be needed to correlate this process to long term tests and to develop equipment for use outside the laboratory.

Another test that was explored with some degree of success uses the attenuation decay pattern of oscilloscope signals as a measure of coating-surface characteristics. To make this a useful test method would require considerably more research and correlation and equipment development.

PREFAILURE EVALUATION TECHNIQUES  
FOR MARINE COATINGS

SECTION A

## SECTION A

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**PREFAILURE EVALUATION TECHNIQUES  
FOR MARINE COATINGS**

**.PREAMBLE**

## REFAILURE EVALUATION TECHNIQUES FOR MARINE COATINGS

### PREAMBLE

### INTRODUCTION

Section A of this document, in four parts, "Prefailure Evaluation Techniques for Marine Coatings", covers specific aspects of the program. Part I discusses ship painting problems with reference to present practices and trends for the future, as indicated by on-site visits to shipyards, paint suppliers, etc. Part II is a manual of testing procedures for appraising quality, and performance potential of ship coatings. Part III describes a literature review of methods for evaluating coatings, and Part IV describes a laboratory study of some new test method. This information was assembled for the U. S. shipyards.

The objective of this program has been to define appropriate laboratory tests to evaluate the probability of premature failure of ship coating systems. This was accomplished by exploring existing coating tests and examining the possibility of devising new tests which, in conjunction with each other, will assure the shipbuilder whether or not premature failure of coatings or coating systems will occur. From this a test manual was prepared for use in the shipyards and by the paint companies and ship owners (Part II of this document). It includes not only the techniques for appraising the quality of the coating system applied in the yards, but also the techniques for appraising the performance potential of new coating system.

### PHILOSOPHY OF PAINT TESTING

The number of test methods for evaluating the quality and performance potential of organic coatings is quite large because the types of coatings and their uses are so extensive. Many of the test methods are described in ASTM



Procedures, Government Specifications, technical publications, trade bulletins, etc. However, there are also many unpublished tests which have been designed by producers and users of coatings in the attempt to obtain better unity between laboratory test results and the performance potential of a coating in a specific end use.

Tests for coatings are designed for use in maintaining quality control and also appraising the potential of the coating for a given end use. For quality control, it is necessary that the tests be performed very quickly. More time is allowable for appraisal of performance potential of a new or unknown coating, but here again the search is always for quicker methods.

In some cases it is possible to perform quick tests which give positive indication of the suitability of a coating for a given use. However, where the end use requirement includes long-term performance in a difficult environment, correlation with short-term laboratory tests becomes difficult.

It is common practice in the laboratory to design the test for greater severity in some key conditions so that the coating will fail in substantially less time than in actual service. For example, temperature may be higher or fluctuated over a wider range, UV light may be more intense or continuous, humidity may be higher and more continuous, chemicals may be of higher concentrations, voltages may be higher, etc. The difficulty lies in correlating the early failure with actual performance because failure mechanisms may not be the same under the more severe, accelerated test conditions as they are in actual service. To help solve this problem, coatings of unknown performance are generally tested simultaneously with the coatings of known performance. If the unknown performs better in all the accelerated tests, it is assumed to be better than the control. Even so, it is very unusual to place a new coating into service based solely on laboratory tests. Some field testing is nearly always performed before adopting a new coating.

The selection of laboratory accelerated tests requires a great deal of judgment. The inexperienced sometimes select tests which have little or no relationship to the end use requirements, and disqualify a good coating on the basis of a meaningless test; or they may over-estimate performance potential on the basis of good test results. Some highly experienced coatings formulators, or users of coatings may, on the other hand, have a tendency to dispute the usefulness of any accelerated test. Nevertheless, the accelerated tests have great value if properly selected and used.

#### METHODOLOGY IN PREPARATION OF PAINT TESTING MANUAL

The study of testing procedures for coatings systems fell into two segments: (1) testing for quality control within the shipyard and (2) testing to appraise the performance potential of a new and untried coating system.

While some of the same tests may fit each category, there are also differences in objectives and procedures which result in different requirements for test methods in order to meet the objectives.

When testing for quality control in the shipyard, it may be assumed that the coating system has already been selected on the basis of its known performance. Testing is, thus, done to insure that everything is as it should be. Of necessity, only quick testing procedures can be used.

When testing to determine the performance potential of a new or unknown coating, more involved and time-consuming methods are both necessary and allowable. Measuring such properties as viscosity, weight per gallon, percent nonvolatile, flash point, etc, while meaningful in quality control, is of little value in predicting service life of unknown materials.

It has been necessary to rely heavily upon the existing test methods in setting up the procedures for both quality control and prediction of service life. However, laboratory appraisals were made of some new or little used methods to help appraise their potential as new coatings evaluation procedures.

Visits were made to a number of carefully selected shipyards to discuss testing procedures for metal surfaces, coating materials, and the applied coating system. At the same time, information was obtained regarding limitations imposed on coatings evaluation under shipyard conditions. Information was also gathered on coatings test methods by visits to the major suppliers of marine coatings in the United States. The suppliers were questioned about their quality control procedures and the methods used for appraising performance potential of new coatings. They were also asked to describe the coatings application conditions which should be controlled in the yards, and what tests could be used to determine if these controls have been satisfactorily employed. Their suggestions for testing the metal surfaces to insure the best performance potential of the coatings were also sought.

In addition, interviews were held with recognized marine coatings experts not employed by the yards or paint companies, such as Government employees and ship owners. They, too, were questioned about testing procedures for marine coatings.

A review of the technical literature pertaining specifically to naval and ship coatings was included in the program. This was paralleled by a survey of methods currently being used by shipbuilders, marine architects, marine paint suppliers, ship operators, and U.S. Navy installations. This survey helped to disclose the more significant methods of evaluating expected service life of ship coatings. These methods were then critically examined in light of the broad experience of the project personnel in this area. Particular attention was given to procedures that could be used for either of three purposes; (1) surveillance of the evaluation of a new coating material for possible use in ship applications, (2) the quality of applications procedures, and (3) evaluation of the present state of deterioration of a coating in service.



**PREFAILURE EVALUATION TECHNIQUES  
FOR MARINE COATINGS**

**PART I - THE SHIP PAINT PROBLEM**

## PREFAILURE EVALUATION TECHNIQUES FOR MARINE COATINGS

### PART I- THE SHIP PAINT PROBLEM

#### DESCRIPTION OF PROBLEM

Some aspects of the ship paint problem appear very complex. Problems differ between new construction and repair situations, and the many different areas of a ship represent totally different painting situations. In addition, a host of factors can complicate painting such as poor climate or weather conditions, cost cutting, inadequate yard facilities, an unsuitable attitude toward painting, and owner's goals and attitudes not commensurate with quality coatings.

Painting, itself, has only recently emerged from an art to a science. However, not all shipyards have kept pace with this transition. The problems of ship painting may be viewed differently from the standpoint of the three main parties involved in new construction; the owner, the yard, and the **coating Supplier**. Therefore, all of the knowledge acquired concerning coatings technology and application must be examined from the perspective of these three parties and the specific problems which each of them face.

To address the problem of ship painting, it was felt that a complete understanding of present shipyard practice was an absolute necessity. This was accomplished by an ambitious series of on-site visits to obtain present practice information.

With this "present practice" foundation in hand, it was possible to comment objectively on the roles of the ship owner, the shipyard, and the paint supplier. These comments are aimed at developing a most necessary understanding and interrelationship between these three parties so that a better end product will result from this rapport.

#### ON-SITE VISITS

An effort was made to visit most major U. S. shipyards and also obtain a good sampling of visits with coating suppliers, ship owners, and miscellaneous people involved in shipyard painting. Forty-two contacts were made during this on-site visit program, consisting of 16 shipyards, 13 coating suppliers, and 13 miscellaneous contacts ranging from ship owners to organizations having a broad interest in marine matters. A list of these contacts is given in Appendix I-A-1. It should be formally noted that all persons contacted were eager to enter into the spirit of the program, and were completely open in offering all information requested. This spirit of cooperation can only be interpreted as an encouraging sign for future progress in the shipbuilding industry.

Information obtained from these visits formed the basis for the discussion of Present Practices, which follows.

### PRESENT PRACTICES

Present practices in ship painting are discussed below from the somewhat critical viewpoint of a coatings chemist, as developed from the experiences of on-site visits. Each part of the coating system including application procedures are discussed separately.

#### Steel Surface Preparation

Preparation of the steel plate for painting varies considerably according to the capabilities of the yard and attitudes of the people involved. In new construction, the objective is generally to blast to near-white metal. In doing this, it is important to obtain the desired blast profile, and then apply the prime coat immediately before the steel can rust. It is generally accepted that there can be no compromise in surface treatment if the full potential of modern coatings is to be realized.

A common practice in the yards today is to closely follow the surface preparation with an application of primer. Automatic grit or shotblasting is often used in front of an automatic paint spray facility. This is an attractive approach in yards where there is much precutting and stockpiling of plate. It is also desirable in wet climates, especially where all storage is outside.

Another approach to surface preparation favored by some yards starts with removal of mill scale before the plate is stored in the yard. The light rust layer which forms during yard storage supposedly tempers the steel and can be removed by an additional blasting operation after construction of subassembly. At this point, the procedure varies with climate. In wet and high humidity climates, the subassemblies may be placed in a blast chamber where the ricocheting action of steel shot provides the desired blast profile to all surfaces. In the humid Gulf area, Ingalls-Litton uses a 56 x 56-foot chamber which can accommodate 100-ton subassemblies. On the wet, Northeast coast, General Dynamics operates a similar multiple abrader facility which can accommodate 80-ton assemblies. Some yards, such as Bethlehem Sparrow's Point, in addition to their automatic blasting and priming facility, have constructed closed sheds which allow manual blasting of some subassemblies,

However, in the balmy, dry climate of the Pacific Southwest, yard personnel feel that there is no need for this elaborate engineering. Within the bounds of EPA requirements, subassemblies are simply blasted and painted outdoors.

In some smaller yards, materials are purchased already blasted and shop-primed. This is a satisfactory procedure if used in combination with adequate attention to quality-upon-receipt and to repair of rust-damaged areas at time of use.

Most yards, regardless of size, are aware of the necessity for proper surface preparation of the steel plate. However, in practice, few controls may be employed on an hour-to-hour, or even a day-to-day basis to insure that the surface profile is within the desired range, the abrasive is within the desired size range, the blasting dust and residue is removed from the metal surface, and the thickness of primer is within the desired range. Generally, heavy reliance is placed on visual observations.

When operated properly, automatic blasting consistently produces acceptable products in both cleanness and profile. However, as previously mentioned, inspections are often delinquent in both frequency and quality. Manual blasting, on the other hand, is always at the mercy of the worker's experience and capability, his understanding of the task, his production quota, and the yard's production schedule. A common and serious inadequacy is time delay between blast and prima coating, which may result from circumstances ranging from equipment breakdown to lunch breaks.

Some yards use sand and are unaware of the resultant blast profile or of the potential health hazard. Most yards are aware of the relationship of sand or grit size distribution to blast profile, but seldom control the size range of the abrasive. Regular sieve analysis of the abrasive would result in the control of the blast profile. Better education and motivation of the worker could add some additional measure of quality control.

### Coatings Application

Paint application is often abused in the shipyard. Most yards possess and use modern equipment such as airless spray. However, in some yards it is apparent that only a few men per crew have been instructed in proper use of the equipment. The bulk of the painters are interested only in obtaining the quickest possible coverage. Painting may be jeopardized by a worker's misguided conscientiousness in applying many times the desired film thickness.

The average worker on a paint crew does not appear to have a thorough understanding of how his own adjustment of paint to spray viscosity will influence the difference between wet and dry film thicknesses. Thus, all viscosity adjustment should be done in the paint shop; not by painters themselves. The painters also lack understanding of the proper use of most application equipment, and how to use wet and dry film thickness gages. Obviously, coating suppliers and equipment manufacturers should be instrumental in spearheading a continuing education program for the man who will actually use the brush, roller, or spray gun.

Often-heard comments regarding painters reflect the poor quality of the available labor pool and the low priority assigned to the painters within the transient labor pool. Moreover, few men are willing or are even capable of working on a paint crew for an extended period of time. The obvious answers to these charges would seem to lie in better wages to attract better quality workers plus improved safety and working conditions to eliminate existing health hazards.

### Priming

Agreement seems to be universal regarding the tremendously important role which primers have in quality of the coating system. Responsible personnel in many yards feel that shop priming is the best way to protect steel in the yard and subsequently provide the basis for a high-quality coating system. Others feel that shop priming results in unnecessary problems centering around the yard's approach to welding. If a yard can successfully weld over a shop primer, then little criticism is usually heard. However, some yards feel that the primer must be blasted off the plate before welding; for example, before joining stiffeners onto plate. This situation must be resolved by a weld-coating education program or by adopting an effective blast just prior to painting the subassembly.

The phase of the MARAD program addressing itself to weld primers is under way at another laboratory at the time of this writing. This study will undoubtedly shed much light on formulation and handling requirements for preconstruction primers.

Some yards are now applying an epoxy-polyamide system-which meets the new U.S. Navy Specification MIL-P-24441. Comments are heard that this system does not require a primer because the first or prime coat is formulated over the same epoxy-polyamide composition. However, good practice demands that the first coat be treated as a primer.

All paint suppliers recognize the necessity of selecting a primer which will be compatible with the entire paint system; for example, with the anticorrosive midcoat, and decorative or functional topcoat. Therefore, combinations of untried materials should never be applied in the shipyard. It generally falls to the owner to approve the coating system which will meet his needs. It is his choice to either select an inexpensive primer for expected short-term use, or a premium material for quality performance. However, he is also dependent on the coating supplier and the yard, both for advice and proper execution of his directives. Unfortunately, there are times when the ship owner may appear to be unconcerned, and the yard representatives may not take the responsibility for a high-quality primer application.

### Painting

Factors which affect painting quality generally overlap with previous remarks concerning coatings application and quality control. However, one aspect of the painting problem appears to be of serious magnitude for all yards and, to date, remains unresolved. This is the need for facilities for controlled atmosphere painting. As noted before, the Pacific Southwest can probably be excluded from these remarks because of favorable climate.



There is no facility in the United States which can conduct inside painting on a daily full production basis. Most major yards can accommodate limited painting inside and many more now routinely paint in sheds.

In the personal interviews, there was almost universal agreement that weather is one of the most limiting factors in obtaining consistently high-quality coatings on ships. The inadequacies of shed painting in a high humidity atmosphere are obvious. Limited facilities now available for inside painting represent only a meager effort at resolving a major shipyard painting problem. No comments are necessary on the justification for not possessing facilities for controlled-atmosphere painting because costs of such facilities are very high. Facilities which tolerate time delay between blasting and painting and those which require outside transport between work areas cannot be considered desirable.

A valuable study on the above mentioned problems was performed under The National Shipbuilding Research Program. Its title is "Cost Effectiveness Study of Weather Protection for Shipbuilding Operations." It consists of 2 volumes and was published by the Todd Shipyards Corporation in April 1974. (oo)

Some foreign yards are ahead of the U. S. yards in providing facilities for painting indoors. Consequently, these yards now offer higher quality ship painting than is attainable in some U. S. yards.

#### Quality Control Procedures

Quality control procedures are presently as diverse as the yards who employ them. On one hand, there are yards which perform essentially no quality control testing of any part of the paint system. These yards may depend upon the ship owner or paint manufacturer to have a paint man in the yard to oversee whatever quality control can be employed. On the other hand, there are some U. S. yards which are quality control conscious, and who have independent QA (Quality Assurance) personnel in addition to the paint crew, owner's representative, and paint supplier's representative. These yards may also have an active laboratory program of evaluating the various coatings offered to them to determine their performance potential before they are even approved for use in the yard.

A major problem encountered in present practice is the poor image suffered by the paint QA man. In bad times, he may be one of the first men to leave; and among the last to get rehired when things improve. Usually, these duties are then absorbed by another QA man who has no firsthand knowledge of coatings. There is an unfortunate attitude in some yards to the effect that time delays and extra money required to maintain an adequate QA force are prohibitive. Owners have not insisted in a substantial coatings quality control program in the yards and the paint suppliers may prefer to remain silent in this respect.

The owner should be aware of potential problems which can exist even in situations where the QA man and paint crew work in harmony. Almost without exception, tremendous emphasis is placed on maintaining construction schedules. If construction is behind schedule, painting usually suffers, with or without a QA force.

### Interrelationship of Ship Owner-Yard-Coating Supplier

A high-quality ship coating job is of great concern to the ship owner, construction yard, and coating supplier. The owner is concerned with the lowering of costs of ship operation by extending time between drydocking for paint. The yard is concerned about overall quality of construction from a competitive viewpoint. The coating supplier is also concerned about quality from a competitive viewpoint for he wishes his coatings to be selected in preference to another suppliers.

In spite of this great concern, too little attention has been paid in the past to making the special efforts necessary to obtain the highest quality coating job on new merchant ships. Indeed, the three interested parties may not even have met at the beginning of a contract to determine the type of paint job desired or to commonly define the role of each party involved in obtaining the highest quality coatings application. Meetings of this type are bound to result in higher quality ship painting. Such meetings should result in a better understanding of initial costs versus long-term costs, and the possible advantages to be gained by some increase in the initial painting costs where necessary to decrease subsequent costs of maintenance.

Comments on the roles of each of these three parties, as noted below, should assist in obtaining this essential bond of common understanding.

#### Role of the Ship Owner

A prime concern of the owner is construction of the specified vessel by a specific date at an acceptable and specified cost. In this respect, his immediate objective is to retain the proper naval architect and yard to design and build the ship.

The owner may not be fully aware of the role of modern marine coatings in meeting his long-term objectives. With the larger vessels, the function of modern protective coatings in extending periods between drydocking becomes critical and it behooves the owner to be as coatings knowledgeable as possible.

The prime requisite of the owner is to understand and plan for the increased importance of paint in ship construction. Once this is truly understood it will be easy to communicate this thinking to the yard. The "cost versus performance" concept must be understood, to ease the fears of both the yard and the owner for the increased costs of performing ship painting properly in the yards.

In the initial, preconstruction meeting of the three concerned parties it is the responsibility of the owner to define his needs to the satisfaction of the other two parties. That is, allowances must be made for the geography and type of service, anticipated drydocking schedules, and desired service life of all coating systems.

Retaining an owner's paint representative in the yard who understands the importance of "quality coating systems of proven performance properly applied" is essential. Conversely, it is not acceptable to retain a yard representative who, although an expert engineer and knowledgeable in coatings, might subordinate painting to construction schedules.

Selecting a shipyard which does not place major importance on painting is detrimental to the interests of the owner. A yard's coating technologist should have shutdown authority similar to the heads of any other construction department.

The ship owners must become aware of the great influence they possess in being able to insist upon a strong coating application specification in each contract. However, the owner must also be willing to pay for the added cost. Emphasis must be placed on the use of coating systems of proven service for each ship area with no concession being made for interchanging components (primers, anticorrosive midcoats, topcoats). Coating systems of proven performance which meet the needs of the owner should be specified for all parts of the ship.

It should be noted that many specifications are drafted today which, on paper, would meet the above criteria. However, enforcing these specifications at the present time may be nearly impossible. If a "no painting under unfavorable weather conditions" clause is to be inserted, many yards would be unable to take the contract unless the ship owner is willing to accept the delays and pay the increased costs. However, the ship owner is in an excellent position to apply pressures for upgrading shipyard facilities to include more painting of sub-assemblies indoors.

### Role of the Shipyard

The role of the shipyard is to provide the highest quality ship coating (materials and application) commensurate with the needs of the ship owner, and the facilities and capabilities of the yard. At present, the facilities and capabilities of the U.S. yards vary considerably. Some yards have a modern outlook, while others have changed little in painting procedures and understanding for many years.

The yards with the most up-to-date attitude toward ship painting have carefully planned and executed procedures for maintaining quality control. This includes carefully selected methods for testing the coating materials, and for checking their application in the yard. Some also have their own active testing programs designed to compare the performance of paint systems offered to them by the paint companies for the various parts of the ship. These yards make a great effort to discourage ship owners from specifying paint systems that the yard has been unable to qualify according to their own demanding requirements. If the ship owner can be brought to realize the tremendous importance of painting, it will be expedient to maintain as efficient a paint department in the yard as possible.

In preference to listing, shortcomings commonly encountered in present practice, it should be more meaningful to mention several changes which could help to make all yards competitive in the future. This includes

- (1) Elevation of paint department to major department status
- (2) Hiring of college graduate coatings technologists to administer paint department
- (3) Maintaining an on-going education program for painters
- (4) Elevation of labor status of painters to obtain more capable personnel
- (5) Provision for adequate inspection of each phase of the coatings operation
- (6) Provision for facilities necessary to insure good coatings technique throughout the year
- (7) Maintenance of at least a minimum laboratory effort.

Each of these seven points bears further elaboration.

Paint Department Status. Paint department status may be the "key to many of today's problems. Even in the circumstance where all phases of yard painting conform to good coatings practice, a consistent premium job can best be guaranteed if painting is elevated to its proper status. Painting should have status equal to other construction departments in the yard.

Coatings Technologist. Special technical personnel must direct the coatings" department. Every yard is well supplied with graduate engineers, but graduate chemists with special coatings experience are a rare exception. However, the graduate coatings chemists are needed to effectively utilize today's sophisticated coatings technology, head up a quality control laboratory, and provide a common level for interdepartmental communication.

Education Programs. Educational programs are desired not only to obtain satisfactory labor, but are equally important in providing worker motivation. Many companies have found an educational program to be highly effective in developing worker motivation or incentive. The educational program should include coatings technology relatable to the individual's involvement in the painting program.

Labor Status of Painters. The labor status of painters is a large concern in obtaining the highest quality ship painting program. Consideration should be given to special incentives to attract skilled painters, and to help them on the job.

Quality Assurance. Methods for quality assurance of ship painting should be defined by each individual yard. However, when the ship owner becomes knowledgeable concerning selection and application of materials, and the coating supplier reinforces this information, there will be little tolerance for anything less than a high-quality ship painting program in the yard. At that point in time, a coatings quality assurance program will become a necessity in all yards.

Facility Upgrading. Facility upgrading is necessary in many yards to accomplish the best paint possible. The rate at which this will come about depends upon the effort expended by each yard to modernize their painting procedures.. Today, an important consideration for every yard is "controlled atmosphere painting", as discussed below under Future Trends.

Lab Facilities. Laboratory facilities do not have to be elaborate but must be sufficient to insure that all suppliers maintain strict control over their products and not stray from their Quality Conformance Tests. Paint samples must also be checked to insure that they have not degraded during storage and to assure that no mistakes have been made in manufacture, labeling, thinning for application, etc. If qualified coatings technologists are aboard, little effort will be required to provide for the necessary routine evaluations. However, the more progressive yards may also prefer to carry out their own coatings qualification testing programs.

Incorporation of the above procedures into a yard's operations should enable the yard to compete strongly in the world shipbuilding community insofar as ship painting quality is concerned. However, it will still be of the utmost importance to initially define the needs of the owner; and then work in concert with the other two concerned parties--the ship owner and the coatings supplier.

### Role of the Coating Supplier

The role of the coating supplier starts with the proper evaluation of his materials. Test methods and complete data, should be available to potential customers. Sales representatives should be aware of the long-term consequences of over-enthusiastic embellishments of data sheets.

At the initial meeting between owner, yard, and coating supplier, an invaluable service can be performed by recommending several coating systems which bracket the established needs of the owners. An equally invaluable service can be made by insisting on use of the complete system on which test data are available in preference to recommending; for example, just topcoats for already-purchased anticorrosives.

If the initial agreement allows for the supplier's representative to be present in the yard, he should direct his efforts toward helping maintain good marine coatings practices. The combination of the owner's coatings representative, the yard's QA force, and the supplier's representative should provide the expertise and inspection potential for near flawless work.

Few yards have laboratories capable of running even routine checks on incoming materials. Consequently, it is presently left to the supplier to maintain batch-to-batch QA and even to oversee the coatings application in the yard. The major suppliers are conscientious in this respect,, but the burden of quality control should not be borne by the supplier alone.

Initially, all three parties must be agreed that a coating system conforms to the required qualification tests. Individual batch samples should be submitted to the yard along with sufficient batch data to maintain quality control. The quality control tests are discussed in Part II of this document.

### TRENDS FOR THE FUTURE

Within the scope of present practice there is no universal "best way" to approach ship painting. Today, each part of each job in each yard must be considered separately, and painting adapted to the existing localized conditions.

It is visualized that a drastic change will be accomplished by doing almost all painting indoors in the shops where subassemblies are prepared. This is now a reality in some European yards and a worldwide trend appears to be materializing in this direction. Domestic yards will probably find that they will have to follow this trend to remain competitive in the quality of their ship painting. As controlled-atmosphere painting becomes commonplace, it will be possible to obtain maximum potential for any selected coating system and a "best **way**" will quickly follow.

Alongside this development, the shipbuilding industry will see the area of painting raised from today's role of stepchild and given major status in the yard. Owners and yards will recognize the extreme importance of "quality-tested, premium coatings systems which are applied properly" and the special significance this bears to economics of ship operation. Recognized coatings technologists will head the painting efforts in all yards. The importance of their position will allow them to act with authority similar to the heads of other yard departments.

In the very near future, there may be new pressures felt from ecologists who advocate removal of organic solvents and "toxic" or "hazardous" materials from all paints. Sandblasting and the amount and kind of materials spray-released into the atmosphere are already under attack in some areas. Therefore, Paint materials will undoubtedly change and present application methods will be modified to accommodate the new compositions. Coating suppliers and government programs are actively seeking answers to these problems, and their solutions will be absorbed into tomorrow's painting practices. In any event, these changes will be more readily adapted if painting is done indoors.

The performance potential of marine coatings systems has improved dramatically in the past couple of decades. However, inadequate application procedures have often held them back from realizing their full potential.

The life of paints on modern ships will improve as these premium materials are applied under optimum conditions. This will encourage regulatory bodies to further extend times between drydockings for inspection and repair, and thereby provide the economic justification for these changes.

APPENDIX I-A

LIST OF ON-SITE VISITS



LIST OF ON-SITE VISITS

<u>Shipyards</u>	<u>Personnel Contacted</u>
Avondale Shipyards, Inc. New Orleans, Louisiana	Wayne Smythe Coatings Coordinator
Bethlehem Shipbuilding Hoboken Yard Hoboken, New Jersey	John Marra of Sea-Land Service, Inc.
Bethlehem Sparrow's Point Shipyard Sparrow's Point, Maryland	David Bloodgood
Her Majesty's Dockyard Esquimalt, British Columbia Canada	LCDR Cecil Baker Arthur Ives
Ingalls-Litton Shipyard Pascogoula, Mississippi	Ben S. Fultz, Coatings Manager Neal Dickens, Paint Chemist G. Alexander, Q.A. R. Zitner, Chief, Engineering C. L. Rector, Paint Superintendent
Lockheed Shipbuilding Seattle, Washington Harbor Island Facility	Russell J. Cook, Asst. to Pres. D. O. Macduff, Materials Chief Ralph Smith, Director, Q.A. Paul Wentink, Chief Weld Engineer David F. Smith, Industrial Prods. Div.
West Bank Facility West Bank Repair Yard	A. O. Anderson Robert Forbell, Manager
Mare Island Naval Shipyard Vallejo, California	John Saroyan, Head, Paint Lab Jesse Neal, Ship Evaluations and Specifications Section Hang Deer, Head, Dev. Section Matt Fountain, Head, Research Section
National Steel and Shipbuilding Company San Diego, California	J. J. McQuaide, Plant Manager H. C. "hoc" Castle, Painting and Sandblasting Superintendent B. Miller, Health and Safety Advisor C. Milton, Engineer R. Law, Chief, Q.A.

Shipyards

Newport News Shipbuilding and Drydock  
Company  
Newport News, Virginia

Norfolk Shipbuilding and Drydock Company  
Norfolk, Virginia

Puget Sound Naval Shipyard  
Bremerton, Washington

Todd Shipyards Corporation  
Galveston Division  
Galveston, Texas

Todd Shipyards Corporation  
Los Angeles Division  
San Pedro, California

Todd Shipyards Corporation  
Seattle Division  
Seattle, Washington

Paint Companies

Ameron  
Corrosion Control Division  
Brea, California

Carboline Corporation  
St. Louis, Missouri

Devoe & Reynolds  
Division of Celanese  
Newark, New Jersey

Du Pont Company  
Philadelphia, Pennsylvania

Enjay Specialties Lab  
Houston, Texas

Personnel Contacted

William Briggs, Marine Coatings  
Specialist

J. R. Herndon

R. Mcknight, Q.A. Division  
W. Wilson, Q.A. Division  
J. Potter, Supt., Paint Department

Ralph Amselmi, General Manager  
Roy Reilly, Paint Foreman  
Frank Coss, Asst. Paint Foreman  
Tony Conde, Sales Representative

Herb Chatterton, Chief Engineer  
Bill Lester, Chief Engineer, Welding

Robert L. Smith, Paint Superintendent

Personnel Contacted

Daniel H. Gelfer, Director of  
Research and Commercial Development

John Montle, Director of Research  
Daniel R. Leritz, Testing Department

John D. Wite, Research Director

Monro Willey, Research Chemist  
A. Sprout, National Product Manager,  
Transportation Finishes  
R. S. Heisler, Tech. Serv. Rep.,  
Transportation Finishes

Dr. Ron Beers  
Dr. E. Curtis  
E. F. Group, Jr.

Paint Companies  
Continued

International Paint Company  
Union, New Jersey

International Paint Company  
South San Francisco, California

Mobay Chemical  
Pittsburgh, Pennsylvania

Mobil Chemical  
Edison, New Jersey

PPG Industries  
Pittsburgh, Pennsylvania

PPG Industries  
Houston, Texas

Porter Coatings  
Division of Porter Paint Company  
Emeryville, California

Standard Paint and Varnish Company  
Harvey, Louisiana

Todd Chemicals, Inc.  
Seattle, Washington

Personnel Contacted

James M. Drubel, Plant Manager  
Robert Wilkinson, Research  
Howard Richardson, Marketing

Grant Johnson, Exec. Vice Pres.

Charles Hixenbaugh, Marine Coatings

Herb Barry, Group Leader,  
Maintenance & Marine Laboratory

William Ravenda  
.

**Gil Repko**  
.

John B. Heymes, Technical Director  
Dwight Cole, Field Service Engineer  
Pat Lilley, Marine Coating Sales

Fred C. Kinsler, Technical Director  
Wayne Smythe, Coatings Coordinator

Jutson Todd  
Verne Todd

<u>Miscellaneous</u>	<u>Association</u>	<u>Personnel Contacted</u>
Defence Research Establishment Pacific Her Majesty's Canadian Dockyard Esquimalt, B. C., Canada	Research Laboratory	Ralph Barer, Section Head W. Art Anderton Richard Sewell Jack Carson
Lloyd's Register of Shipping	Marine Assurance	C. O. Smith
Lockheed Oceanics Division San Diego, California	Allied Shipbuilding Problems	Peter Benson
LTV Advanced Technology Center Dallas, Texas	General Marine Interest	Dr. F. W. Fenter
Nickum and Spaulding Seattle, Washington	Ship Owner's Repre- sentative	Merlin L. Needles Marine Surveyor
Nomicos Shipping London, England (contact in Todd Galveston yard)	Ship Owner	Keith Earvey Private Consultant
R. W. Little Company San Diego, California	Surface Preparation (sandblasting)	R. W. Little
Scripps Institution of Oceanography La Jolla, California	General Oceanographic Interests	Prof. Dennis Fox
Sea-Land Service, Inc.	Ship Owner	John Marra
Standard Oil Company of California Richmond, California	Ship Owner	Joel E. Davis Materials Technologist Coatings Specialist
U.S. Naval Civil Engi- neering Laboratory Materials Science Division Port Hueneme, California	Marine Coatings	Dr. Robert L. Alumbaugh Senior Project Scientist
U.S. Navy Development and Training Center Materials Yard San Diego, California	General Marine	
Zapata Offshore/Zapata Marine Houston, Texas	Ship and Offshore Drilling Rig Owner	Dr. David Bruce Marine Coatings

THE  
END

PREFAILURE EVALUATION TECHNIQUES  
FOR MARINE COATINGS

PART II - MANUAL OF TESTING PROCEDURES  
FOR MARINE COATINGS

PREFATLURE EVALUATION TECHNIQUES  
FOR MARINE COATINGS

PART II - MANUAL OF TESTING PROCEDURES  
FOR MARINE COATINGS

SEGMENT I - TESTING FOR QUALITY CONTROL  
IN THE SHIPYARDS

Quality control tests are desirable for each part of each finishing system for each area of the ship. The parts of the finishing systems are metal surface preparation, anticorrosive coatings, other intermediate coatings and topcoats (including antifouling paints). Moreover, such factors as intercoat adhesion and coatings application technique are extremely important to performance of the paint system and are, thus, considered a part of the system. It is desirable to measure metal surface contour (after blasting) and cleanliness (detection of rust, scale, blasting residue, and other soil). Measurement of the amount of moisture on the surface is also important for some coatings.

For quality control of coatings materials, it is desirable to measure such properties as flow characteristics (viscosity or rheology), weight per gallon, nonvolatile content, drying time, flash point, (pigment dispersion) fineness of grind, color, gloss, and others.

To measure quality of coatings application, it is desirable to apply appropriate tests to the painted parts of the ship (bottom, boottop, topside, decks, ladders, bulkheads, etc). It is also desirable to measure coating thickness, continuity, adhesion, and other properties relatable to the performance requirements for these various areas. However, procedures employed must fit within the realm of practicability. Quality control testing procedures must be accomplishable in short time, and be capable of performance in the shipyard.

While it might be desirable to standardize quality control procedures in all the yards, it is highly unlikely that this could be accomplished. Instead, each yard must decide what methods of quality control can be best employed to fill its individual needs. This manual is offered as a guide to the yards in establishing their quality control procedures.

It must be reiterated that quick, quality-control test procedures are not adequate for appraising the performance potential of a new or unknown coating. More extensive, and longer-term testing is necessary to qualify a coating for use, as described in Segment 2 of this manual. Quality control testing (as described in Segment 1) is done to assure that the coating materials used in the yard are up to standard, and that steps in the coatings application are done properly.

### Metal Surface Condition - Quality Control

Testing methods must assure that the metal surface preparation is up to the desired, or specified quality. It is well recognized by corrosion and coatings experts that proper metal surface preparation is critical to marine coatings performance. Best results are obtained when the metal surface is completely clean, and free of scale, rust, and soil. The suitability of lesser preparation for any given coating system must be established through experience gained in actual use of the coating system, or by employing carefully selected, long-term laboratory testing.

Within the shipyard, visual inspection of the blasted surface by a highly-experienced corrosion-control, or coatings expert is probably the best method of quality control on a frequent basis. However, his visual inspection should be supported by pictorial standards, and instrumental measurement of surface contour, as discussed in Method 1-1 (Appendix II-A1). Out in the yard, it will be expedient to use the Keane-Tator Comparator described in Method 1-1. In the shop, a more accurate measurement of surface contour can be obtained using the Profilometer or Talysurf instruments described in Method 1-1.

The surface roughness should be measured on a frequent basis to control the blasting operation; and maintain roughness within the specified range for the coating system in use. Excessive roughness is difficult to cover and may actually produce voids or pinholes in the coating.

Quality of the surface preparation can also be maintained (once the desired procedure has been established) by controlling the blasting operation to assure that everything is done uniformly at all times. This is especially applicable with automatic machine blasting in the shop. Careful control must be maintained over the kind and size of abrasive used, blasting speed, and all other conditions of the blasting operation.

Pictorial standards for steel surface preparation have been prepared by the Swedish IVA Corrosion Committee, and jointly approved by SSPC (Steel Structures Painting Council), ASTM (American Society for Testing and Materials), and the Swedish Standards Association. Other standards are "SNAME" Abrasive Blasting Guide for Aged or Coated Steel Surfaces. (See Method 1-2 in Appendix<sup>1</sup>II

Whenever questions exist about the suitability of weather conditions for painting, measurements should be made of relative humidity in the area using a hygrometer. Calculations should then be made of the dew point using the procedure described in Method 1-3 (Appendix II-A1). The temperature of the metal surface should be measured using a simple dial thermometer. If the metal temperature is within a few degrees of the dew point, it will be advisable to halt the painting. A more detailed discussion of weather suitability for painting is also given in Method 1-3 (Appendix II-A1).



### Coating Materials - Quality Control

The quality control testing of coating materials should be sufficient to insure that the materials are of the specified (or usual) standard, that the correct materials have been received, and that no mistakes have been made by the coatings supplier during manufactures packaging, or labeling. By this quality assurance testing, the yard can determine if the coating is likely to perform the same as it has in the past.

The testing should also include examination of the materials when ready for application.. This should be done to insure that the materials are still up to standard, and have not changed during long storage. The tests should also show whether or not the materials have been properly stirred, thinned, and otherwise prepared for application.

The test methods discussed below are useful in quality assurance of coating materials. However, each of the properties of the coating as measured by the tests must have been previously defined for a batch of coating which was proven to be suitable for its intended service. Proving the coating for service involves long-term testing, as described in Segment 2 of this manual.

The following tests as described in Appendix II-A2 are suggested for wet samples of coating materials for quality control.

- (1) Wet Paint Sampling - Method 2-1 (Appendix IZ-A2)
- (2) Condition in Container - Method 2-2
- (3) Weight per Gallon - Method 2-3
- (4) Viscosity (Consistency) - Method 2-4
- (5) Fineness of Grind (Pigment Dispersion) - Method 2-5
- (6) Flash Point - Method 2-6
- (7) Reducibility and Dilution Stability - Method 2-7
- (8) Drying (or Cure) Time - Method 2-8
- (9) Pot Life (Catalyzed Materials) - Method 2-9
- (10) Application Characteristics - Method 2-10
- (11) Nonvolatile Content (by weight) - Method 2-11
- (12) Pigment and Filler Content (by weight) - Method 2-12.

Quality control of solvents may be maintained by running the following tests:

- 0 Flash Point - Method 2-15 (Appendix II A-2)
- 0 Compatibility with Coating Material - Method 2-7

- 0 Distillation Range - Method 2-16
- 0 Evaporation Rate - Method 2-17
- 0 Specific Gravity - Method 2-18
- 0 Refractive Index - Method 2-19.

Toxicity of the coating materials and reducing solvents is of vital concern to the shipyard. However, toxicity of these materials cannot be readily determined by the yard; therefore, manufacturers' certification statements regarding toxicity should be requested for each material used in the yard.

The wet coating material should be reduced as indicated by the supplier and spray-applied to test panels using Method 6-1 (Appendix 11-A6). The dried, or cured, coating should be given the following tests as described in Appendix 11-A3 :

- (1) Color - Method 3-1
- (2) Gloss - Method 3-2 (where applicable)
- (3) Hardness - Method 3-3
- (4) Appearance - Must appear similar to same kind of coating from a previously acceptable batch. Standard panels should be retained for this purpose.

The tests actually selected from the above list for checking quality of a given coating will depend upon the kind of coating being examined and other factors, such as the need to settle dispute. For example, tests for color and gloss may be eliminated for primers or undercoats because these are appearance factors which are unimportant in this type of material. However, judgments based on experience are necessary because even here a large difference in color or gloss could indicate error in batch preparation.

Since the coating manufacturers normally do not check nonvolatile content, pigment content, and percent binder on all their batches of marine coatings the yard may also prefer to skip these measurements. However, whenever there are any questions regarding material quality, these tests are very helpful as additional checks. Therefore, it is necessary to establish values in these tests for each marine coating that is approved for use in the yard so that subsequent batches can be checked for comparison as a quality control procedure whenever desired.

The minimum list of tests for any wet sample of marine coating material used in the yard should include the following:

- (1) Condition in can - Method 2-2
- (2) Weight per gallon - Method 2-3
- (3) Viscosity - Method 2-4

- (4) Drying time - Method 2-8
- (5) Application characteristics - Method 2-10
- (6) Flash point - Method 2-6
- (7) Hardness of applied coating - Method 3-3
- (8) Appearance of dried coating by a visual inspection  
(compared to a standard retained panel).

Obviously, using more tests on a marine paint results in a higher degree of quality control, and less chance for an error in materials which could impair performance. Excessive testing, on the other hand, adds to costs.

#### Coatings Application - Quality Control

Proper application is extremely important to the performance of a coating system. However, this is an area where simple testing cannot be employed sufficiently to assure coatings performance. Heavy reliance must be placed on good practices, which generally depend upon experience, judgment, and conscientiousness, rather than testing after the fact. Some tests, such as wet film thickness measurements, Method 3-4 (Appendix II-A3), can be used to very good advantage, and are a must in quality control during coatings application.

Tests can also be employed to determine if materials have been mixed and thinned properly. Weight per gallon and viscosity of the material as ready for spray will help in this respect. Methods for measuring these properties have already been mentioned and are described in Appendix II-A2. However, poor equipment maintenance, dry spraying, improper overcoating (either too soon or too long after the previous coat), and other poor practices are not controllable by testing after the fact.

Improper scaffolding and poor lighting can result in poor coatings application with perhaps wide variations in thickness from area to area. While thickness variations can be measured, the damaging effects of the poor application may be impractical or impossible to correct afterward. Consequently, it cannot be stressed too strongly that coatings application be carefully supervised by trained coatings technologists. The actual application should be carried out by skilled applicators who are properly trained in spray application and maintenance of equipment.

Awareness by all concerned that painting is an extremely important Part of ship construction is Paramount to good painting Practices. The quality of the paint job has great bearing on future maintenance costs, and does effect the efficiency of ship operation.

### The Applied (Finished) Coating System

Some of those interested in ship painting have suggested from time to time that the great need is for a "black box" test which can be quickly applied to the finished paint system. Ideally, the test would indicate immediately whether or not the paint system is up to quality, and will perform as expected.

No "black box" test exists for measuring immediately the performance potential of an applied coating system. Even gross deficiencies in procedures, such as application over a poorly prepared surface, can be very difficult to spot with existing test methods. None of the coatings specialists interviewed during this program could suggest an approach to the development of a "black box" test.

It is interesting to consider the possible advantages to be gained if a suitable "black box" test could be realized. The advantages would seem to lie in the area of fixing blame. Determining after the fact that the applied paint is not up to quality will do nothing to change the quality of that paint unless the paint is removed and the area repainted. Consequently, it is apparent that the control be employed earlier if the quality of the paint system is to be assured.

Wet film thickness measurements made frequently while the painting is in progress can be very helpful in quality control. Methods for measuring both wet and dry film thickness are given in Method 3-4 in Appendix II-A3. By monitoring wet film thickness, adjustments in application conditions can be made to correct any deviations from the desired thickness. Obviously, the standard for any given coating must have been established previously by laboratory evaluations or prior experience gained from actual usage of the paint on ships. Generally, the coatings manufacturer has predetermined the amount of dry coating needed, and has specified the minimum thicknesses acceptable. Thus, it is necessary only to relate wet film to dry film thickness for the given material.

Dry film thickness measurements are useful in determining if the job has been done correctly. The methods for measuring wet and dry film thickness are described in Appendix II-A3.

However, dry film thickness measurements made long after the painting is done suffer from the same deficiency as the "black box" test. Paint thickness measurements must be made at frequent intervals while the painting is in progress so that adjustments can be made as the work proceeds. The measurement of inadequate thickness after the job is finished is helpful only if another coat of paint can be worked into the construction schedule. Even then, it may not be possible to make amends if intercoat adhesion is impaired by overcoating a material which has cured too long to obtain a good bond between coats. If this condition exists, it is wise to use a light "brush blast" before overcoating.

SEGMENT 2 - TESTING TO PREDICT PERFORMANCE OF NEW  
COATINGS OR COATINGS OF UNKNOWN POTENTIAL

New and unproven coating systems need to be tested to (1) determine their adaptability to shipyard methods and conditions, and (2) predict their serviceability in the intended use.

Tests are needed to relate measurable properties of coating materials to their suitability for application in the yards. It is necessary to consider such properties as viscosity (for spray, roll, or brush application) and rheology-solids relationships for film build without sagging. Other factors to consider include flash points, toxicity, hiding, color, etc. Like quality control tests, the methods used to determine suitability of a coating for shipyard application conditions should be quick and relatively simple.

The prediction of service life from short-term laboratory tests presents the most difficult part of the coating evaluation program.

The present state of the art indicates that the use of controlled accelerated methods to accomplish failure can give valuable information regarding the durability of coating films. However, the data so obtained should be used as guideposts, and the results should be confirmed by actual exposure to the expected service conditions.

Coatings film failure can be of four general types; (1) chemical, (2) physical, (3) mechanical, or (4) electrical. Frequently, the deterioration is a combination of two or more of these general types. Interrelations are such that synergism often occurs, giving increased failure beyond that normally expected.

The relative importance of the different methods of failure is dependent upon the specific use of the paint. For example, automotive finishes must retain good appearance, whereas ship paints must maintain protection. In fact, in certain applications, such as antifouling paints, a controlled sloughing is frequently desired in order to expose fresh surfaces that are toxic or discouraging to marine organisms; and development of poor appearance in these paints is of little consequence.

Recent research studies in the field of organic coating deterioration have been in the direction of analyzing data using the Arrhenius relationship, which says that a deteriorating force has an exponential relationship to the rate of deterioration. This is true where only one force and only one failure pattern is involved.

This means that, if one can isolate a single force, and numerically designate the rate of failure, a log plot of time versus force can allow a graphical prediction of service life for that particular force. However, when more than one force, or more than one failure mode occurs, the problem becomes complex and the log relationship is no longer linear. It is, therefore,

apparent that heavy reliance will need to be placed on evaluation procedures already available, and which have a demonstrated utility. This does not mean, however, that new techniques are to be ignored. Actually, laboratory methods geared to the use of any new technique which has the potential of shortening the evaluation time are to be encouraged.

The coatings manufacturer performs laboratory and field testing to prove his new materials suitable for intended service. This is a critical part of his coatings formulation program. Some fleet operators may also perform their own testing of new and untried coatings offered to them by the paint companies. Certainly, their actual experiences with marine coatings on ships should be used advantageously in future selection of coating systems.

Those yards which wish to maintain the very highest standards of coatings performance will also wish to do their own testing to determine which coatings shall be approved for use in the yard. While doing this, they will establish the values for the properties of the coating, which will be measured in the quick quality control tests on each subsequent batch of coating. These tests must be designed to fit the individual needs and requirements of coatings for each part of the ship.

#### Quick. Preliminary Testing to Predict Performance of New and Unproven Coatings.

Yard testing of a new and unproven coating should first take account of the quick tests that can be used to determine adaptability of the material to shipyard methods and conditions. These tests may include the following:

- (1) Application Characteristics - Method 2-10  
(Appendix II-A2)
- (2) Drying or Curing Time - Method 2-8
- (3) Flash Point - Method 2-6
- (4) Toxicity (certification supplied by manufacturer).

Procedures to be used in performing these tests were discussed previously under "Coating Materials Quality Control". Because toxicity tests are difficult to perform, the yard will probably rely on assurance given by the manufacturer.

It is also wise to test each new coating carefully to determine if it meets the specifications established by the manufacturer. The same quick tests discussed in Segment 1 (for quality control) are applicable. If the sample supplied does not meet the manufacturer's own specifications, there is little point in subjecting it to long-term testing to determine its performance potential.

From the above discussions, it is obvious that the first step in testing any marine coating for purposes of predicting its performance potential is to subject it to quick tests similar to those used in quality control. Sufficient tests should be used to insure that the coating meets the specifications supplied by its manufacturers government specifications where applicable, or standards supplied by the ship owner. The following list of tests is applicable:

- (1) Weight per gallon - Method 2-3 (Appendix 11-A2)
- (2) Viscosity - Method 2-4
- (3) Fineness of Grind - Method 2-5
- (4) Flash Point - Method 2-6 .
- (5) Condition in Container - Method 2-2
- (6) Drying or Curing Time - Method 2-8
- (7) Pot Life (if applicable) - Method 2-9
- (8) Application Characteristics - Method 2-10
- (9) Nonvolatile Content - Method 2-11
- (10) Pigment and Filler Content- Method 2-12
- (11) Reducibility - Method 2-7
- (12) Color and Gloss of Dried Coating (where applicable) - Methods 3-1 and 3-2
- (13) Hardness of Coating Film - Method 3-3
- (14) Storage Stability - Method 6-6 (Appendix II-A6)

#### Environmental Simulation Testing to Predict Performance of New Coatings

Laboratory testing of new coatings in order to predict performance in actual service requires the use of test conditions which simulate some of the most important features of in-service conditions. It is not possible to incorporate all environmental factors into the laboratory testing of marine coatings. Many of the tests used are not as severe as actual service conditions. At the same time, there is an obvious desire to obtain results as quickly as possible. Therefore, some test conditions may be added which are actually foreign to the in-service use. For example, some companies use hot-water immersion as a screening test for bottom and boottop paints; or topside paints may be tested by continuous immersion which is not an actual in-service condition.

Whatever procedure is used for testing a new coating, it is most important to test it alongside a coating of known performance. Only by comparison of performance of the new coatings with known coatings is it possible to make meaningful extrapolation of laboratory results to in-service Performance.

### Preconstruction Primers

Ordinarily, primers should be evaluated as a part of the paint systems for which they are designed. The evaluation of paint systems for various parts of a ship are described elsewhere. However, for preconstruction primers, an additional procedure is necessary. The preconstruction primer needs also to be evaluated for its own protective merits, and its suitability for overpainting after prolonged outdoor exposure. It must also be tested to determine its effect on welding.

The primer-first needs to be evaluated for application properties commensurate with shipyard use. The following tests should be made:

- (1) Viscosity and/or Flow - Method 2-4 (Appendix II-A2)
- (2) Spraying Characteristics - Method 2-10
- (3) Drying Time - Method 2-8
- (4) Flash Point - Method 2-6
- (5) Toxicity (certification should be supplied by manufacturer).

Other tests are desirable to determine if the primer samples supplied are in line with the manufacturer's specifications. These tests should include

- (1) Weight per gallon - Method 2-3
- (2) Percent Nonvolatile - Method 2-11.

Still another test is highly important for preconstruction primers. This is a test for weldability - Method 3-8 (Appendix II-A3)

If the above tests are satisfactory, the primer should then be subjected to the long-term testing necessary to determine its performance potential. This should include storage stability - Method 6-6 (Appendix II-A6). The primer should also be applied to steel test specimens prepared as described in Method 6-1 (Appendix II-A6). After drying for at least the minimum time specified by the supplier, primer panels should be overcoated with each of the marine paint systems of interest to the shipyard (for all the parts of the ship). Each of these marine paint systems should then be subjected to the tests available for paints for that part of the ship, as described elsewhere in this manual.

Another set of primed panels (not painted) should be tested as follows:

#### Outdoor Exposure - Method 4-1 (Appendix II-A4)

This can be done on exposure racks suitably located within the yard or at other appropriate marine exposure sites. The panels should be exposed for a minimum of 6 months, or if time permits, for the maximum time that primed steel may be exposed in the yard before painting. These panels should then be overcoated



with the various marine paint system of interest to the yard. This is to Simulate conditions wherein only the primer protects the plate during ship construction and before the various marine coatings are applied.

Before overcoating, the primed panels should be examined as follows:

Corrosion Resistance - Method 5-1 (Appendix II-AS)

Adhesion - Method 3-5 (Appendix II-A3)

General Appearance - Method 5-3 (Appendix II-A5)

After overcoating, the specimens should be subjected to the tests appropriate for the particular part of the ship for which the coating system is designed. These methods are described elsewhere in this manual.

An accelerated evaluation of the primers may be desirable for screening a large number of candidates to a workable number for the longer-term, simulated service testing. Tests useful for this purpose are

- (1) Salt Fog Testing - Method 4-3 (Appendix II-A4)
- (2) Cleveland Condensing Cabinet - Method 4-5
- (3) Accelerated Weathering - Weather-Ometer - Method 4-2.

The panels subjected to the above tests should be examined at the intervals indicated for each test method. They should be examined for corrosion resistance, adhesion, and general appearance using the methods listed above for panels exposed outdoors.

#### Exterior Hull Coatings--Underwater

Each coating material that makes up the underwater hull coating system should first be evaluated for application properties commensurate with shipyard use. The following tests should-be used:

- (1) Spraying Characteristics - Method 2-10 (Appendix II-A2)
- (2) Drying Time - Method 2-8
- (3) Flash Point - Method 2-6
- (4) Toxicity (certification should" be supplied by manufacturer).

Other tests are desirable to determine if the coating samples supplied are in line with the manufacturer's specifications. These tests should include

- (1) Viscosity - Method 2-4
- (2) Weight per gallon - Method 2-3

## II-12

- (3) Percent Nonvolatile - Method 2-II
- (4) Color - Method 3-1 (Appendix II-A3)
- (5) Gloss - Method 3-2
- (6) Fineness of Grind (pigment dispersion) - Method 2-5.

If the above tests are satisfactory, the coatings should be examined for storage stability according to Method 6-6 (Appendix II-A6). The coating should also be applied to test panels according to the manufacturer's instructions regarding coating thickness, number of coats, drying time between coats, etc. A guide for preparation of test panels is given in Method 6-1 (Appendix II-A6) .

titer drying the final coat for the specified time, the coating system (on test panels) may be subjected to laboratory testing for convenience. Again, the **new** coating of unknown performance potential should be tersed alongside a control coating system of known performance. The following laboratory tests are applicable:

- (1) Hardness - Method 3-3 (Appendix II-A3)
- (2) Abrasion Resistance - Method 3-7
- (3) Adhesion - Method 3-5
- (4) Simulated Seawater Immersion - Method 4-7 (Appendix II-A4)
- (5) Cleveland Condensing Cabinet - Method 4-5
- (6) Salt Fog Testing - Method 4-3.

Other laboratory tests may be added to this list to obtain more comparisons of coatings performance. These additional tests will add to the reliability of the performance comparisons between the new coatings and a control coating of known performance:

- "(7) Cyclic Testing Cleveland Condensing Cabinet and Freezing - Method 4-6
- (8) Spinning Disk - Seawater - Sand Slurry - Method 4-15.

The panels from the immersion should be examined periodically according to the schedule indicated for the test method. The following observations should be made (as described in the Appendices):

- (1) Corrosion Resistance - Method 5-1 (Appendix II-A5)
- (2) Adhesion - Method 3-5 (Appendix II-A3)
- (3) Hardness - Method 3-3 (usually only at end of test)
- (4) General Appearance - Method 5-3 (Appendix II-A5)

While the above tests are useful in predicting service life of a new coating, the tests only approximate actual service on ship bottoms. Moreover, they give no indication of fouling resistance of the bottom coating system. Therefore, the yard may prefer to go immediately to immersion test; in; actual seawater. The following tests are useful in this respect:

- (1) Seawater Immersion Raft Tests - Method 4-8 (Appendix II-A4)
- (2) Test Panels on Rotor Apparatus - Method 4-10
- (3) Synthetic Seawater Immersion of Panels in a Hydrodynamic Double Chambered Tank - Method 4-11
- (4) Test Panels Attached to Ship Hull - Method 4-13
- (5) Patch Tests on Ship - Method 4-12.

Again, the panels or patches should be examined periodically as described above. However, fouling by marine organisms is to be added to the list of examinations. Rating of fouling accumulation is discussed in Test Method 6-10 of Appendix II-A6.

Coating to be used in conjunction with cathodic protection should also be evaluated according to Test Method 4-15 in Appendix II-A4.

Coating to be used for the boottop area should follow the same evaluation procedure described above with the following exceptions:

- (1) Accelerated Weathering - Method 4-2 (Appendix II-A4) should be added to the laboratory tests--or Method 4-4 which cycles panels from the Weather-Ometer to Salt Fog.
- (2) Panels immersed in seawater should be tested according to Method 4-9, Discontinuous Seawater Immersion, wherein they are removed periodically from the water and exposed to sunlight for a few days, and returned to the seawater.

#### Exterior Hull Coatings - Topside and Deck Coatings

Each coating material that makes up the topside paint system (or is to be used on decks) should first be evaluated for application properties commensurate with shipyard use. The following tests described in the Appendices should be used:

- (1) Spraying Characteristics - Method 2-10 (Appendix II-A2)
- (2) Drying Time - Method 2-8
- (3) Flash Point - Method 2-6
- (4) Toxicity (certification to be given by supplier).

Other tests are desirable to determine if the coating samples supplied are in line with the manufacturers' specifications. These tests (described in the Appendices) should include

- (1) Viscosity - Method 2-4 (Appendix II-A2)
- (2) Weight per gallon - Method 2-3
- (3) Percent Nonvolatile - Method 2-11
- (4) Color - Method 3-1
- (5) Gloss - Method 3-2
- (6) Fineness of Grind (pigment dispersion) - Method 2-5.

If the above tests are satisfactory, the coatings should be applied to test panels according to the manufacturers' instructions regarding coating thickness, number of coats, drying time between coats, etc. A guide for preparation of test panels is given in Method 6-1 (Appendix II-A6).

After drying the final coat for the specified time, the coating **system** (on test panels) may be subjected to laboratory testing. Again, the new coating of unknown performance should be tested alongside a control coating system of known performance. The following laboratory tests are suggested:

- (1) Hardness - Method 3-3 (Appendix II-A3)
- (2) Abrasion Resistance - Method 3-7
- (3) Adhesion - Method 3-5
- (4) Salt Fog - Method 4-3 (Appendix II-A4)
- (5) Accelerated Weathering- Method 4-2
- (6) Cleveland Condensing Cabinet - Method 4-5.

Other laboratory tests may be added to obtain more comparisons of coating performance. These additional tests will add to the reliability of the performance comparisons between the new coatings and a control coating of known performance.

- (7) Cyclic Testing between Cleveland Cabinet and Freezing - Method 4-6
- (8) Cyclic Testing between Accelerated Weathering and Salt Fog Exposure - Method 4-4.

The panels should be examined periodically according to the schedule indicated for the test method. The following observations should be made:

- (9) General Appearance - Method 5-3 (Appendix II-A5)
- (10) Adhesion - Method 3-5 (Appendix II-A3)
- (11) Protective Qualities: Corrosion - Method 5-1.

Longer-term testing will involve outdoor exposure in a marine environment: Method 4-1 (Appendix II-A4). Spot or patch tests on selected parts of the topside or superstructure of ships are also helpful: Method 4-I-1. Again, the panels or patches should be examined periodically as described in the given test methods, making the observations listed above.

### Interior Coatings

Coatings. for ship interiors, like all other ship coatings, should be examined for application properties commensurate with shipyard use. The following tests described in the Appendices should be used:

- (1) Spraying Characteristics - Method 2-10 (Appendix II-A2)
- (2) Drying Time - Method 2-8
- (3) Flash Point - Method 2-6
- (4) Toxicity (certification to be given by supplier).

Other tests are desirable to determine if the coating samples supplied are in line with the manufacturer's specifications. These tests described in the Appendices should include

- (1) Viscosity - Method 2-4
- (2) Weight per gallon - Method 2-3
- (3) Percent Nonvolatile - Method 2-11
- (4) Color - Method 3-1 (Appendix II-A3)
- (5) Gloss - Method 3-2
- (6) Fineness of Grind (pigment dispersion) - Method 2-5.

If the above tests are satisfactory, the coating should be applied to test panels according to the manufacturer's instructions regarding coating thickness, number of coats, drying time between coats, etc. A guide for preparation of test panels is given in Method 6-1 (Appendix II-A6) of this manual.

After drying the final coat for the specified the, the coating system (on test panels) maybe subjected to special laboratory testing, depending upon the area of use in the ship.

For living spaces, a great deal of importance should be placed on appearance factors and cleanability. The following tests will be applicable:

- (1) Color Change - Fading - Method 6-3 (Appendix II-A6)
- (2) Washability or Scrub Testing - Method 6-4.

For engine rooms, it may be desirable to test for the following:

- (1) Resistance to Oil and Grease - Method '6-7
- (2) Washability or Scrub Testing - Method 6-4.

Other special tests may be employed to meet special requirements of interior coatings such as

- (1) Fire Resistance (flammability) - Method 6-5.

#### Tank Coatings (Linings)

Tank linings, like all other ship coatings, should be examined first for application properties commensurate with shipyard use. The following tests described in the Appendices should be used:

- (1) Spraying Characteristics - Method 2-10 (Appendix II-A 2)
- (2) Drying Time (or cure time) - Method 2-8
- (3) Flash Point - Method 2-6
- (4) Toxicity (certification to be given by supplier).

Other tests are desirable to determine if the coating samples supplied are in line with the manufacturer's specifications. These tests (described in the Appendices) should include:

- (1) Viscosity - Method 2-4
- (2) Weight per gallon - Method 2-3
- (3) Percent Nonvolatile - Method 2-11
- (4) Fineness of Grind (pigment dispersion) - Method 2-5.

If the above tests are satisfactory, the coating should be applied to test panels according to the manufacturer's instructions regarding thickness, number of coats, drying time between coats, etc. A guide for preparation of test panels is given in Method 6-1 of Appendix II-A6 of this manual.

After drying the final coat for the specified time, the coating system (on test panels) should be subjected to laboratory testing according to Method 4-14 in Appendix II-A4.

The immersion testing described in Method 4-14 involves cycles of exposure to salt water, aromatic fuel, hot seawater, and hot seawater spray (to simulate tank cleaning). Other applicable tests relate to patching of damaged areas in coating.

If aircraft fuel, chemicals, or other liquids are to be carried in the tank, separate immersion tests should be made for each product as described in Method 4-14. It is highly desirable that control coatings of known performance be tested alongside the new coatings if suitable controls are available. Exposure periods in the products should be at least 6 months, and preferably 1 year. After exposure, the panels should be examined as follows:

- (1) General Appearance - Method 5-3 (Appendix II-A5)  
and evidence of fluid contamination as indicated  
in Method 4-14
- (2) Corrosion Method 5-1 (Appendix II-A5).





APPENDIX II-A1

TESTS TO BE APPLIED TO METAL SURFACES  
TO DETERMINE SUITABILITY FOR PAINTING

APPENDIX II-AI

TESTS TO BE APPLIED TO METAL SURFACES  
TO DETERMINE SUITABILITY FOR PAINTING

Method 1-1. Profile or Surface Contour (Roughness)

Method 1-2. Standards for Cleanliness

Method 1-3. Suitability for Painting: Weather Factors, Temperatures  
and Humidity

## II-A1-1

### Profile or Surface Contour (Roughness) Method 1-1

A convenient method for estimating surface profile after blasting is to use the Keane-Tator Comparator. The complete comparator unit, consists of a reference disc and a 5X illuminated magnifier with a magnetic disc holder. The disc is composed of five sections with nominal anchor pattern depth of 0.5, 1, 2, 3, and 4 roils. It may be used as either a visual or tactile reference.

The instrument is placed on the metal surface. Visual comparison is made between the metal surface and reference surfaces (of known roughness) within the viewing field. By making the best visual match, a good approximation can be made of surface contour. This approximation is good enough for most shipyard purposes.

An alternate method for measuring height of profile of the anchor pattern is described by SSPC(1). In this method, a flat spot is ground on the blasted surface until the bottoms of the pits are almost reached. The height may then be measured with a micrometer depth gage graduated to read 0.001 inch, and with a base having a bearing length of 2 inches and measuring rod of 3/32-inch diameter.

Surface roughness may also be measured accurately by instruments such as different profilometers<sup>(2)</sup> (3)(4) or the Talysurf (5). These instruments are designed to measure and record **surface contours**. When using the Talysurf with a High Resolution Pickup (which has a special sharp diamond stylus and reduced stylus pressure), measurements can be made of very fine surfaces, such as gage blocks. This instrument is capable of measuring surface roughness from 0.00002 inch to about 1/4 inch.

The instruments produce plots of surface contour of the type shown below (Figure 1) as the stylus travels over the metal surface.

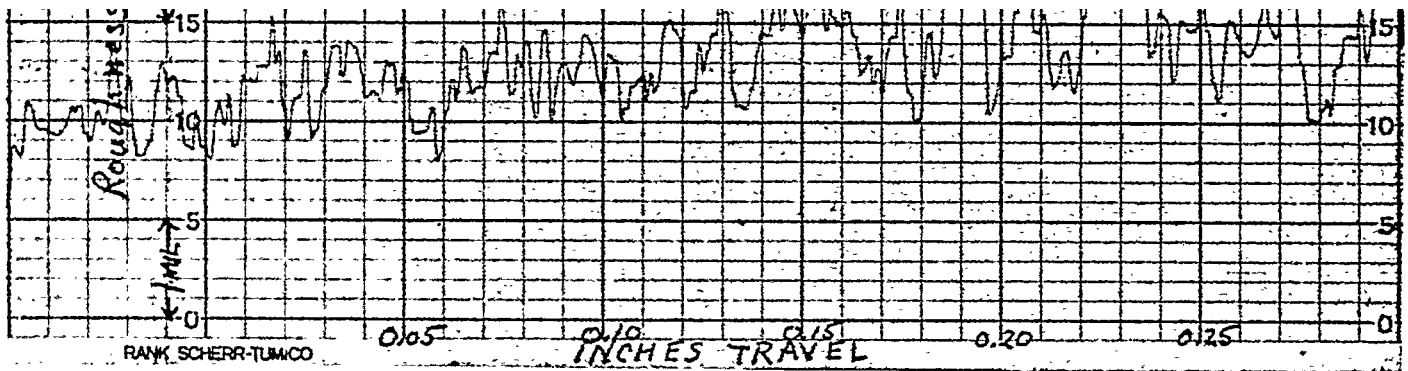


FIGURE 1. SAMPLE PLOT OF SURFACE CONTOUR:  
PLOT PRODUCED BY PROFILOMETER

- (1) Steel Structures Painting Manual, Volume I (Revised 1966), page 116, published by Steel Structures Painting Council.
- (2) Physics Research Company, Ann Arbor, Michigan
- (3) BSRAProfilometer
- (4) Monotester R
- (5) Manufactured by Taylor-Hobson Division of the Rank Organization, Leicester,

Metal Surface Standards for Cleanliness  
Method 1-2

Pictorial standards for steel surface preparation have been prepared and issued in 1967 by Swedish IVA Corrosion Committee and jointly approved by

- o Steel Structures Painting Council,
- o American Society for Testing and Materials, and
- o Swedish Standards Association.

Pictorial surface preparation standards consist of a series of color prints. They represent various conditions of ferrous surfaces prior to painting. The standards show the following initial surface conditions before surface preparation:

- (1) Steel surface covered completely with adherent mill scale, but little or no rust
- (2) Steel surface which has begun to rust with mill scale beginning to flake
- (3) Steel surface from which the mill scale has rusted away with pitting visible
- (4) Steel surface from which the mill scale has rusted away with little or no pitting visible

The various grades of thoroughness of surface preparation are also represented as follows:

- (5) Manual cleaning, light
- (6) Manual cleaning, thorough
- (7) Manual cleaning, very thorough
- (8) Blast cleaning, light
- (9) Blast cleaning, thorough
- (10) Blast cleaning, very thorough.

The actual photographs and details of the applicable definitions appear in the test of the photographic reference standards publications book SSPC-Vis 1-63T, available from Steel Structures Painting Council.

Specifications established by the Steel Structures Painting Council are helpful in defining the condition of a blasted steel surface. The following specifications are applicable:

- 0 SSPC-SP5-63 - White Metal Blast Cleaning. This describes a surface completely free of rust, mill scale, and foreign matter or contaminants. If initially agreed upon, SSPC-Vis I-63T or other visual references may be used to supplement this specification.
- 0 SSPC-SP 10-63 - Near-White Blast Cleaning. Describes a blasted surface which is essentially free of rust and scale, but from which the last traces of shadows, streaks, or discoloration have not been removed.
- 0 SSPC-SP 6-63 - Commercial Blast Cleaning. Describes a high degree of cleaning expected to give long life with practically any paint system, but where cleaning is not as thorough as described above. This specification permits the optional use of a visual standard such as SSPC-Vis I-63T.
- 0 SSPC-SP 7-63 - Brush-Off Blast Cleaning. Describes a low cost blast cleaning which only removes loose mill scale, loose rust, and loose paint. This method permits the use of SSPC-Vis I-63T or other visual reference.

A further development are pictorial standards for steel surface preparation prepared and issued in 1969 by The Society of Naval Architects and Marine Engineers and the U. S. Navy and approved by

- 0 Steel Structures Painting Council, and
- 0 National Association of Corrosion Engineers

Pictorial surface preparation standards consist of a series of color plates bound into one handy field manual, SNAME Bulletin 4-9 "Abrasive Blasting Guide for Aged or Coated Steel Surfaces." "A number of different types of shipbuilding steel in various as-is condition as obtained from the mill, storage yard or coated on ships were sequentially sectionally masked and blast cleaned to show their appearance in accordance with Steel Structures Painting Council specifications of Brush-Off, Commercial, Near-White and White Metal Blast Cleaned. By holding the color plate near the ship or steel surface to be evaluated of a particular steel a quick visual comparison may be obtained.

Suitability for Painting: Weather Factors,  
Temperature. and Humidity  
Method 1-3

The control of quality of a marine paint is highly dependent upon weather conditions at the time of painting. The instructions of the paint supplier should be followed carefully regarding limits in temperature and humidity conditions for applying each particular product used in the yard.

High temperature at time of application can cause thinning of the paint, fast evaporation of solvent between gun and metal surface resulting in dry spray, and poor wetting of the metal surface.

Low temperatures can cause thickening of paint, difficulty in spraying, slow drying, and slow curing (of catalyzed systems). Long retention of solvent may also cause the applied coating to sag.

There are temperature limitations beyond which the coating should not be applied. Other variations in temperature should be compensated for by adjustments in reducing solvents; faster evaporating solvents for lower temperatures and slower evaporating solvents for higher temperatures. The paint manufacturer's instructions should be followed in adjusting to these conditions.

Humidity and moisture on the metal surfaces also affect coatings quality. When condensation is visible on the metal surface, painting should be terminated until conditions are again right. However, excessive moisture is not always so readily distinguishable. A fairly safe rule to follow is "do not paint when metal surface temperature is within 1 degree of the dew point".

The metal temperature can be measured with any surface (contact-type) thermometer. One such instrument is supplied by VWR United Corporation(1). The entire metal back of the instrument is sensitive to temperature and is held in intimate contact with the surface to be tested with a magnet clamp.

Humidity should be measured with a sling psychrometer. . This instrument is also available from VWR United Corporation and other suppliers of scientific equipment. The instrument contains two glass-stem thermometers mounted in a mechanism for whirling rapidly by hand. One thermometer is dry (dry bulb) and the other has the bulb covered with a moistened wick (wet bulb). ASTM E-337-62 may be used as a guide in measuring humidity.

The percent relative humidity is determined from the wet and dry bulb reading made after whirling the psychrometer. The humidity can be directly determined from psychrometer charts, using the wet and dry bulb readings. Some instruments include a slide rule-type calculator of relative humidity. However, the wet bulb temperature is the dew point, which is the important temperature to compare with the metal surface temperature.

(1) Regional offices in many cities.

Too low humidity can affect cure of certain inorganic zinc silicate primers. These primers depend upon moisture to hydrolyze the alkyl silicate they contain and form the silica binders liberating alcohol which evaporates. Again, the manufacturers' suggestions should be followed regarding limitations in temperature and humidity at time of application.





APPENDIX II-A2

QUICK OR SHORT-TERM TESTS FOR USE ON  
WET SAMPLES OF COATING MATERIALS

## APPENDIX II-A2

### QUICK OR SHORT-TERM TESTS FOR USE ON WET SAMPLES OF COATING MATERIALS

- Method 2-1. Wet Paint Sampling
- Method 2-2. Condition in Container
- Method 2-3. Weight per Gallon (Density)
- Method 2-4. Viscosity or Consistency
- Method 2-5. Fineness of Grind (Pigment Dispersion)
- Method 2-6. Flash Point of Coatings
- Method 2-7. Reducibility - Dilution Stability
- Method 2-8. Drying (or Curing) Time
- Method 2-9. Pot Life
- Method 2-10. Application Characteristics
- Method 2-11. Nonvolatile Content
- Method 2-12. Pigment and Filler Content
- Method 2-13. Binder Content (Nonvolatile Vehicle)
- Method 2-14. Pigment-Binder Ratio

### Solvents

- Method 2-15. Flash Point of Solvents
- Method 2-7. Compatibility with Coatings (see Reducibility above)
- Method 2-16. Distillation Range
- Method 2-17. Evaporation Rate
- Method 2-18. Specific Gravity
- Method 2-19. Refractive Index

## II-A2-1

### Wet Paint Sampling Method 2-1

F.T.M. Std. No. 141a-2021 and ASTM Special Technical Publication 500 (Gardner/Sward) may be used as a guide.

#### Objective:

To provide representative quantities from each lot, so that it may be ascertained if the material meets the requirements of the covering product specification, and to determine uniformity within a batch that has been packaged prior to inspection.

#### Procedure

Samples shall be taken by or under the immediate supervision of a person of judgment, skill, and previous experience in sampling.

All containers shall be marked with the production batch number, and care taken so that at least one sample is taken from each batch.

With large containers such as tanks or tank cars, three separate 1-quart samples shall be taken, one from the top, one from the bottom, and one from an intermediate point, and then forwarded to the laboratory without mixing.

Precautions must be taken to assure that samples are neither contaminated with, nor altered by any material not representative of the batch being sampled.

Whenever possible, original unopened containers shall be sent to the laboratory. When this is not done, an inspector shall first determine whether the material meets the requirements regarding caking in the container, then thoroughly mix the contents and draw a sample. This sample shall be placed in a suitable container, identified and sent to the laboratory for testing with the inspector's report on caking.

## II-A2-2

### Condition in Container Method 2-2

#### Settling of Pigment

F.T.M. Std. 141a-4208 or ASTM D869-48 may be used as a guide.

#### Objective

To evaluate the degree of pigment settling and ease of remixing of a shelf-aged or stored sample of paint.

#### Procedure

An undisturbed representative container of coating material shall be selected for examination. This to be done for new lots of coating material received at the yard, and also before using materials that have been stored in the yard. The container shall be opened without agitation, and examined without removal of the supernatant vehicle. A spatula or stirring paddle shall be used to determine the extent and character of separation during storage. If a portion of the pigment has separated to form a firm cake on the bottom of the container, efforts will be made by hand-stirring to reincorporate the pigment to form a homogeneous paint. If the sample is rated "0" according to the specification, it is not to be used. A zero rating states "Very firm cake which cannot be reincorporated with the liquid to form a smooth paint by stirring manually".

### Coarse Particles and Skins

F.T.M. Std. 141a-4091 or ASTM D185-45 may be used as a guide.

#### Objective

To determine the amount of skins and agglomerated material in oil-base paints.

#### Procedure

Normally, a simple visual examination of skinning of oil-based materials in the can should suffice to determine if the materials are still usable. However, if there is dispute regarding the amount of skinning, the following procedure may be used.

### II-A2-3

A No. 325 sieve having a diameter of 3- inches shall be thoroughly cleaned and dried-in an oven at  $105\text{ C} \pm 2\text{ C}$ . Cool the sieve in a desiccator and weigh it to the nearest mg. Weigh to the nearest mg a sample containing approximately 10 g of pigment into a 250-ml beaker. Add 50 ml of kerosene and thoroughly mix, breaking up, but not grinding, all lumps with a stirring rod. Wet the sieve with kerosene and slowly pour the contents into the sieve. When the bottom becomes covered, work the liquid through the sieve by gently brushing through the liquid. Rinse all pigment particles from the stirring rod and beaker into the sieve. After the liquid has passed through the sieve, place the sieve in an 8-inch porcelain dish containing 250 ml of kerosene; the sieve should be immersed to a depth of about 1/2 inch. Move the pigment on the sieve by brushing, then raise the sieve and let the liquid run through. Clean the dish, add a new portion of kerosene and repeat the operation until the kerosene passing through the sieve is clear and free of solid particles. Wash the pigment particles from the brush into the sieve with a stream of extraction mixture\*. Finally, wash the kerosene from the sieve with extraction mixture and dry the sieve for 1 hour at  $105 \pm 2\text{ C}$ . Cool the sieve in a desiccator, weigh and calculate the percentage of coarse particles and skins.

\* Extraction mixture: 10 volumes ethyl ether; 6 volumes benzene; 4 volumes methyl alcohol; 1 volume acetone.

Weight Per Gallon or Density  
Method 2-3

References: F.T.M. Std. No. 141a-4184.1 and ASTM D-1475

Objective:

To provide a method for the measurement of density of paints, varnishes and lacquers. Density of coating varies according to the kinds and amounts ingredients used and thus is indicative of holding to correct composition.

Procedure

The weight per gallon cup is available from Gardner Laboratory, Inc.\*. Thoroughly clean the cup with a nonresidual solvent and tare it on a balance capable of weighing to the nearest 0.1 gram. Pour the well-mixed paint, previously adjusted to 23 C, into the cup until it is nearly full, place the cover firmly in place, and wipe off the excess paint which exudes through the hole in the cover. Determine the weight of the paint in the cup in grams, then divide this figure by 10 to obtain the density of the paint in pounds per gallon.

The alternate method, ASTM D-1475, provides for determining density using any size container from 20 to 100 cu cm. This is a general method and involves accurate calibration of the cup and more involved calculations to achieve a higher degree of accuracy than is normally possible with the recommended procedure. However, this is done with some sacrifice in convenience.

\* P. O. Box 5728, Bethesda, Maryland 20014.

Viscosity or Consistency  
Method 2-4

- (1) "Brookfield Viscometer" (preferred method in laboratory)  
References: ASTM D2196-68 and F.T.M. Std. No. 141a-4287
- (2) Ford Cup (alternate method in laboratory)  
References: F.T.M. Std. No. 141a-Method 4282 and  
ASTM D1200-58
- (3) Zahn Cup (preferred method in paint room or out in yard)  
Reference: ASTM Special Technical Publication 500  
(Gardner/Sward)

Objective:

To provide a method for characterizing the flow of a liquid coating material, which may be designated by any of several terms--consistency, body, flowability, or viscosity.

Brookfield Discussion

The "Brookfield Viscometer" is particularly suited for use with coatings that display thixotropic characteristics. Materials having this characteristic tend to "thin out" and flow more readily under an applied force. Thus, they "thin out" when passing through the spray gun and "thicken" on the substrate, to which they have been applied.

The cylinder or disk of the Brookfield is rotated in the test liquid, and the torque necessary to overcome the viscous resistance is indicated by a pointer on the instrument dial. The pointer deflection is proportional to the viscosity. Temperature must be controlled carefully during the entire process because viscosity is temperature related. Generally, the measurements are made at a standard temperature of 77 F (25 C). The Brookfield viscometer is available from Brookfield Engineering Laboratories, Inc., Stoughton, Massachusetts.

Procedure

Lower slowly the affixed spindle until it is immersed to the proper depth. Start the viscometer and take readings at four or more increasing speeds, then again at those speeds decreasing to the starting speed. Shut the viscometer off and allow the sample to stand undisturbed for 2 minutes. Start the viscometer and take a final reading. Report the apparent viscosity in poises in the order in which the readings were taken.

### Ford Cup Discussion

The Ford viscosity cup is an orifice efflux type viscometer used in the laboratory for quality control of paints of known flow characteristics.

#### Procedure

Fill the cup level full with the coating to be tested; then the time required to drain is measured in seconds. Results are reported in seconds for the "Ford" cup used (three cups are available with different orifice sizes). Temperature must be controlled carefully during the process because viscosity is temperature related. The measurements are generally made at 77 F (25 C). Ford cups are available from Gardner Laboratory, Inc.\*.

### Zahn Cup Discussion

The Zahn cup is filled simply by dipping it in the liquid to be tested. Consequently, it is simple to use in the yard. The cup finds widespread use in industry, particularly at the paint application site. The Zahn cup is available from Gardner Laboratory, Inc.\*.

#### Procedure

Dip the instrument into the material to be tested. Withdraw the cup and time the interval in seconds from withdrawal until the stream of material flowing from the cup breaks. This is the consistency in Zahn seconds. There are five orifice sizes. Again, measurements must be made at the specified temperature (usually 77 F or 25 C) because viscosity is temperature related.

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\* P. O. Box 5728, Bethesda, Maryland 20014.



Fineness of Grind (Pigment Dispersion)  
Method 2-5

References: F.T.M. Std. No. 141a-4411.1 and ASTM D-1210-64

Objective:

To measure the degree of dispersion or "fineness of grind" of pigment as dispersed in liquid paint vehicles.

Description

Fineness gages of several arbitrary scales are commonly used by industry; however, most are physically the same. The gage is a hardened steel block approximately 7 inches long, 2-1/2 inches wide, and 1/2 inch thick. The top surface is ground smooth and flat, and contains a groove 5-1/4 inches long and 1/2 inch wide. The groove is uniformly tapered in depth lengthwise from 4 mil. at one end to zero depth at the other. Calibrated graduations are in accordance with depth. A double wedge steel blade is provided as a scraper.

Procedure

Place the clean gage on a level nonslippery surface. The Hegman gage is widely used in the paint industry and is available from Gardner Laboratory, Inc.\*. Place the material to be tested (free of entrapped air) in the deep end of the groove so that it overflows the groove slightly. Hold the blade perpendicular to the block and draw the material down the length of the groove with a uniform motion. Immediately determine the fineness by viewing the gage from the side in such a manner that the paint along the groove where the material first shows a predominately speckled appearance is observed. Note the scale graduation that most nearly corresponds to the paint; report this number as the fineness of grind. Repeat the test for a more accurate reading which is to be made within 10 seconds elapsed time.

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\* P. O. Box 5728, Bethesda, Maryland 20014.

Flash Point of Coatings  
Method 2-6

References: F.T.M. Std. No. 141a-4293 and ASTM D-93-71

Objective:

To determine the flash point of coating materials by use of the Pensky-Martens Closed Cup Tester. Refer to above standards for apparatus specifications.

Procedure

Thoroughly clean and dry the cup before starting the test. The Pensky-Martens Closed Cup is available from Fisher Scientific Company. Charge sample into the cup up to the filling mark. Place the lid on the cup and set the cup in the stove. Insert the proper thermometer and light the test flame. Heat at such a rate that the temperature increases from 1.8 to 2.2 F per minute for materials flashing below 220 F and from 9 to 11 F per minute for materials . . flashing above 220 F. Maintain the stirrer at 250 + 10 rpm. The first application of the test flame shall be made at a temperature of at least 30 F below the expected *actual* flash point. Successive application of the test flame shall be made at specified temperature intervals until the flame application causes a distinct flash in the interior of the cup.. The temperature at which flash occurs is recorded as the flash point. The barometric pressure is recorded, but no corrections shall be made except in case of dispute.

A newer instrument (not covered by above specification) "Sets-Gardner Combustibility Tester" \* is available for measuring the combustibility of paints and coating materials. It is an **open** cup tester reported to be capable of paking a test in just one minute. The instrument can be used for quality control when specification procedures are not called for,

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\* p<sub>au</sub>l N. Gardner Company, Ft. Lauderdale, Florida.

Reducibility and Dilution Stability  
Method 2-7

Reference: F.T.M. Std. No. 141a-4203.1

Objective:

To determine the reducibility of a coating material with the recommended solvent for that material.

Procedure

Dilute the material with the amount of the solvent required in the product specification. The material shall mix readily and easily without excess stirring or shaking. Pour the diluted material into a 100-ml stoppered graduated cylinder and let stand for 4 hours. At the end of the standing period, observe for the following defects: curdling, precipitation, or separation. If doubt exists as to the condition of the material, after the standing period, flow a portion of the material onto a glass panel; defects mentioned above will then be observable.

Drying (or Curing) Time of Coatings'  
Method 2-8

References: ASTM D-1640-69 and F.T.M. Std. No. 141a-4061.1

Objective :

To determine the various stages and rates of film formation in the drying or curing of coatings normally used under ambient conditions.

Procedure

The referenced methods cover procedures for determining the following stages in the drying process: Set-To-Touch, Dust-Free, Tack-Free, Dry-To-Touch, Dry-Hard, Dry-Through, Dry-To-Recoat, and Print-Free. The determination of length of time to reach each of these stages in the drying process may find use in the overall painting operation. However, the Dry-Through time and the Dry-To-Recoat time should be of most use to the yard. The methods used to determine each of these two stages are as follows:

Test specimens are to be prepared in duplicate by one operator properly skilled in the methods to be used. The coating to be tested shall be applied on clean steel panels in accordance with product specifications. The coated panels are to be placed in a horizontal position free from direct sunlight. Care must be exercised to apply a wet film of sufficient thickness to give the recommended dry film thickness expected under actual usage conditions.

For Dry-Through or Dry-To-Handle, the test panel should be placed in the horizontal position such that the operator's arm will be vertically positioned when the thumb is placed on the coating film. Bear down on the film with the thumb exerting maximum pressure and at the same time turn the thumb through an angle of 90 degrees in the plane of the film. The film is considered Dry-To-Handle when no distortion of the film occurs. A film is considered Dry-For-Recoating when a second coat or specified topcoat can be applied without the development of any film irregularities, and the dry time of the second coat does not exceed the maximum specified.

For laboratory determination of drying time of coatings on flat panels, instruments are available which can be used to eliminate some of the subjectivity from the test. One such instrument is the Gardner Drying Time Recorder\*.

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\* Available from Gardner Laboratory, Inc., P. O. Box 5728, Bethesda, Maryland 20014.

## II-A2- U

### Pot Life of Catalyzed Coatings Method 2-9

No federal., ASTM test, or other standard methods were found in the literature specifically designed to measure the pot life of catalyzed coatings. However, Military Specification MIL-P-23236 (Ships) includes a brief description of a method for determining pot life as follows:

"The coatings of the coating system shall be mixed from the components, in accordance with the supplier's instructions> in a suitable container so as to result in approximately one quart of finished material. For routine testing, ambient conditions above 70 F and 50 percent relative humidity shall be satisfactory. For referee tests, 70 F+ 5 F and 80 + 10 percent relative humidity shall prevail. The time between mixing and the loss of adequate brushing and spraying properties shall be determined. Report up to a 48-hour period the actual temperature, humidity, and the time of loss of adequate brushing and spraying properties".

## II-A2-12

### Application Characteristics Method 2-10

#### Spraying Properties

References: F.T.M. Std. No. 141a-4331.1

#### Objective:

To provide a method for checking the spraying properties of coating materials.

#### Procedure

This method is subjective and should be performed only by an individual skilled in using a spray gun. A steel panel 4 by 12 inches shall be cleaned with solvent and the coating to be tested reduced according to product specifications. While spraying, the gun shall be held perpendicular to the panel and moved in a straight line across the face of the panel. The product specification shall state the distance from the test panel to the gun; usually 6 to 8 inches for quick drying materials and 8 to 10 inches for slower drying materials. After spraying, immediately place the panel in a nearly vertical position and observe the wet film for the following: running, sagging, or fogging. The dried film shall be free of the following defects:

- |                |                 |
|----------------|-----------------|
| (1) dusting    | (7) pinholing   |
| (2) floating   | (8) cratering   |
| (3) mottling   | (9) orange peel |
| (4) bubbling   | (10) blushing   |
| (5) wrinkling  | (11) blooming   |
| (6), streaking | (12) silking    |

#### Sag Resistance (Baker Method)

Reference: F.T.M. Std. No. 141a-4493

#### Objective:

To determine the sagging properties of a surface coating. This method may be used for "on the job" testing.

Procedure

The test material shall be applied according to product specifications on the vertical surface to be coated. The test must be run within 2 minutes after application unless otherwise specified. Draw two sets of 8-inch horizontal lines with a sag liner (Figure 2) so that the contact points fall on a vertical line. After a 16-hour aging period (or product specified period), the sagging characteristics shall be rated as follows:

- (1) "No sag" - There is no evidence of paint movement about the sag lines.
- (2) "Very slight sag" - Paint may run part way across either sag line.
- (3) "Slight sag" (unsatisfactory) - Paint runs across the narrower sag line at some point but only part way across the broader sag line.
- (4) "Sag" (failure) - Some portion of the paint runs across both sag lines.

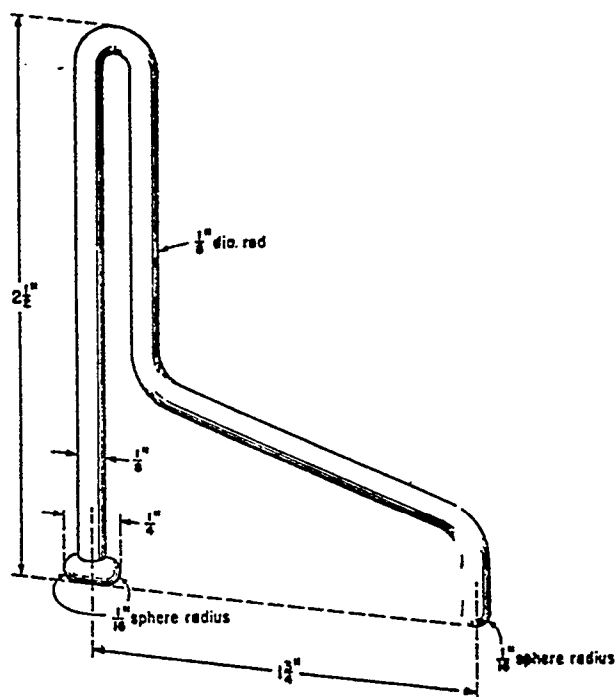


FIGURE 2. SAG LINER

Sag Test (Multinotch Blade)

Reference: F. T.M. Std. No. 141a-4494

Objective:

To provide a procedure for determining the sag characteristics of surface coatings. This is primarily a laboratory method.

Procedure

A multinotch applicator similar to Figure 3 shall be used to lay down at least light strips of coating of graduated thickness. The drawdown shall be made in one continuous movement on a test chart containing both black and white areas. The completed drawdown shall then be immediately placed in a vertical position, with the stripes horizontal, the thinnest strip being at the top. The coating shall be left in this position until dry. The strip which sags sufficiently to cross into the next thicker strip below it shall be considered the strip thickness at which failure occurs.

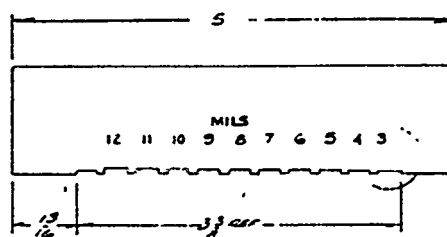


FIGURE 3. MULTINOTCH  
APPLICATOR



## II-A2-15

### Leveling Properties

Reference: ASTM D-2801-69

Objective:

To determine the relative leveling characteristics of liquid coatings. This method is not applicable to unpigmented products.

Procedure

The coating to be tested is applied to a hiding-power chart by means of a special leveling test blade\* designed to lay down the coating in parallel pairs of stripes of varying film thickness. Place the blade on the hiding-power chart and add sufficient coating for a complete drawdown in a puddle immediately in front of the doctor blade. Complete the drawdown and allow it to dry in a horizontal position. Report leveling ability on a scale of "0" to "10" based upon the number of pairs of parallel stripes that have flowed together as illustrated in the photographic standards in ASTM D-2801-69.

\* New York Society for Paint Technology Leveling Test Blade; available from Precision Gage and Tool Company, Dayton, Ohio.

Nonvolatile Content of Paint  
and Paint Materials  
Method 2-11

References: ASTM D-2369-68 and D-214-68, and F.T.M. Std. No. 141a-4041.1

Objective:

To determine the nonvolatile content by weight of solvent-type coatings.

Procedure

Weigh accurately from 0.4 to 0.6 gram of the sample into a tared aluminum foil dish into which has previously been added 2 ml of toluene. Aluminum dishes suitable for this use are available from Fisher Scientific Company. Gently shake the dish while the sample is *being* added to disperse the sample in toluene. Heat the dish for 20 minutes in a forced draft oven at  $110 \pm 2$  C. Remove the samples from the oven, cool in a desiccator, and weigh. Calculate the percentage of nonvolatile matter in the paint:  $\text{Residue (wt after heating) / Sample (wt before heating)} \times 100$ .

Coatings which contain very volatile solvents cannot be accurately weighed while in an open dish because weight keeps changing as solvent evaporates. Coatings of this type should be placed in a syringe, and the syringe weighed before and after charging a sample of coating from the syringe into the dish. The weight of coating in the dish is equal to this difference in weight of syringe.

Pigment and Filler Content  
Method 2-12

References: F.T.M. Std. No. 141a-4021.1 and ASTM Methods D-2371 and D-2698

Objective:

To provide a procedure for the quantitative separation and determination of weight percent pigment content of solvent-based paints and lacquers.

Procedure

Mix the sample to be analyzed until it is homogeneous, then weigh accurately approximately 10 grams of the sample into a weighed centrifuge tube. Add 30 to 60 milliliters (ml) of extraction mixture\*; mix thoroughly with a glass rod, then wash the rod clean with a stream of extraction mixture into the tube. Place the tube in the container of a centrifuge and counterbalance the container of the opposite arm with a similar tube. Centrifuge until the pigment is clearly separated, then decant the clear supernatant liquid. Repeat the extraction twice with approximately 40 ml of extraction mixture. Decant the liquid, then heat (gently at first) over a steam bath to drive off the extraction mixture. The pigment cake should be dislodged from the bottom of the glass tube by tapping on a cloth pad on a benchtop. Dry the tube at 105 to 110 C for 2 hours. cool, weigh, and calculate the percentage of pigment:  $\text{Residue (wt after heating)} / \text{Original Sample} \times 100$ .

\* Extraction Mixture: Mix 10 volumes of ethyl ether, 6 volumes of benzene, 4 volumes of methyl alcohol, and 1 volume of acetone. Other extraction mixtures are listed under F.7.M. Std. No. 141a-4021.1, Reagents.

## II-A2-18

### Binder Content Method 2-13

The binder (or nonvolatile vehicle) content of a coating can be determined by difference between (1) total nonvolatile and (2) pigment and filler content. The total nonvolatile content of the coating is determined by Method 2-11. The pigment and filler content is determined by Method 2-12. Subtracting the weight of pigment from the total weight of nonvolatile content in the coating gives the weight of binder solids. The percent binder is then calculated as  $\text{weight binder} / \text{total weight original coating} \times 100$ .

## II-A2-19

### Pigment-Binder Ratio Method 2-14

The pigment-binder ratio (by weight) is determined by using pigment content (weight) as determined by Method 2-12 over the binder content (weight) as determined by Method 2-13.

Flash Point Reducing Solvents  
(Tag Closed Tester)  
Method 2-15

References: F.T.M. Std. No. 141a-4291 and ASTM D-56-70 and ASTM D-1310

Objective: To determine the flash point of volatile thinners.

Procedure

Obtain a Tag Closed Flash Tester\* meeting specifications described in the above references. Place the apparatus on a steady table and shield for protection from drafts and strong light. Test the apparatus for proper operation by determining the flash point of paraxylene (flash point check grade)\*\* prior to making the initial sample determination.

Place 50 ml. of sample into the test cup. The temperature of the sample shall be such that, when thermal equilibrium has been established, the reading of the sample cup thermometer is at least 16 F below the expected flash point. Attach the cover lid to the bath collar and insert the thermometer. Record the equilibrium temperature of the sample and the barometer pressure. Light and adjust the size of the test flame. Apply heat to the bath so that the temperature of the sample rises at a rate of  $1.8 \pm 0.2$  F per minute. When the sample temperature reaches 9 F below the expected flash point, introduce the test flame into the cup and immediately bring it up again. Record the time and temperature of the first introduction of the test flame. Repeat the application of the test flame after each 1 F rise in temperature until a distinct flash is observed. Record the time and the temperature of the sample when the flash point is reached. Repeat the test with a fresh sample according to the test procedure as described, except the test flame shall be introduced for the first time when the sample temperature is 10 F below the flash point of the initial test. Average the test results and correct for barometric pressure if necessary.

A newer instrument, "Setaflash Flash Point Tester"\*\*\*, is available which can make flash point tests in 2 minutes. This new mini-sample. "Go/No-Go" method has been adopted as a proposed 1P Method of test in the 1972 edition of the 1P Standards for Petroleum and Its Products. This is an alternate method that can be used for quality control when the usual specifications are not called for.

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\* A Tag Closed Flash Point Tester may be obtained from Fisher Scientific Company.

\$\* Paraxylene may be obtained as Flash Point Check Fluid from Special Products Division, Phillips Petroleum Company, Bartlesville, Oklahoma.

\*\*\* Paul N. Gardner Company, Ft. Lauderdale, Florida.

Distillation Range Reducing Solvents  
Method 2-16

References: F.T.M. Std. No. 141a-4301.1 and ASTM D-1078-70

Objective:

To provide a method for determining the distillation range of organic solvents having boiling ranges between 30 and 250 C(86 and 482 F).

Procedure

The distillation apparatus\* shall conform to the specifications described in the above F.T.M. reference. Essentially, the apparatus consists of a 200-ml distilling flask, a condenser, a gas burners a 100-ml cylinder graduated in 1-ml subdivisions, and partial immersion thermometers.

Using the graduated cylinder, measure 100 + 0.5 ml of the sample. Transfer the sample to the flask, allowing the graduate to drain for 15 to 20 seconds. Connect the flask to the condenser and insert the proper thermometer. Place the cylinder at the outlet of the condenser tube such that the condenser tube extends into the graduate at least 25 mm but not below the 100 ml mark. If the initial boiling point of the sample is below 70 C (158 F), the cylinder is to be placed in a transparent bath and maintained at a temperature of 10 to 20 C (50 to 68 F). Place a flat cover on the top of the graduate to prevent condensed moisture from entering the graduate.

Apply heat to the flask so that the first drop of liquid is collected o within 5 to 10 minutes. Record the temperature at which the first drop falls from the end of the condenser as the initial boiling point. Adjust the heat so that the distillation proceeds at a rate of 4 to 5 ml per minute, and move the graduate cylinder so that the condenser now touches the side of the cylinder. Record the temperatures at which 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 95 ml of distillate are collected. Continue distilling beyond the 95 percent point without changing the heating rate, but for no longer than 5 minutes. Record the temperature at any one of the following occurrences: the dry point is reached; there is active decomposition; or there is liquid residue present at the end of the 5-minute heating period. If residue is present, pour into a small graduated cylinder; measure and record the volume as residue. Read the total volume of distillate and record as recovery. Record the difference between 1CJO and the sior of the residue plus recovery as distillation loss. Read and record the barometric pressure. Correct the temperature readings for deviation of the barometric pressure from normal (see tables listed in both references).

---

\* An apparatus suitable for this purpose is available from Precision Scientific Company, Chicago, Illinois.

Report the results in a manner similar to the specifications of the material tested, or report the corrected temperatures at each observed volume and the percentages of residues, recovery, and distillation loss.



Evaporation Rate Reducing Solvents  
Method 2-17

References: F.T.M. Std. No. 141a-4492  
ASTM Special Technical Publication 500 (Gardner/Sward)

Objective: To determine the comparative evaporation rate of any solvent.

Procedure

The Federal Test Method recommends toluene as the comparative standard; however, it should be noted that n-butyl acetate has found wide acceptance as a reference standard. Refer to the product specification for the appropriate reference solvent.

Using a syringe, place 1 gram of sample into a flat bottom, straight-sided, quarter-pint, friction-top can lid placed on an analytical balance. Measure the loss due to evaporation by weighing the pan and its contents at equally spaced time intervals. Repeat this determination with the reference solvent under identical conditions. Plot curves for both materials using weight loss against time. Compare the curves.

The evaporation rate may be assigned a numerical value by using the following equation:

$$\text{Evaporation Rate} = \frac{A}{B}$$

where

**A** = the time for 90 percent weight loss of the reference solvent, and

**B** = the time for 90 percent weight loss of the sample.

Another very simple technique to use as a quality control method is to compare the sample of solvent in question with a retained sample of the same kind of solvent using the following method:

Cut two strips of paper from the same sheet (bond writing paper is satisfactory). The strips should be 1 x 12 inches. Dip one strip into the unknown sample, and the other to the same depth in the retained sample (control). Withdraw both at the same time, hold side-by-side, and observe the drying rate.

Specific Gravity of Reducing Solvents  
Method 2-18

References: F.T.M. Std. No. 141a-4183 and ASTM D-891-59

Objective: To provide a method for determining the specific gravity of solvents and thinners.

Procedure

The references list four procedures for determining the specific gravity of a solvent. There is one method for each of the following types of equipment: a specific gravity balances a hydrometers a pycnometer, and a vacuum pycnometer. The procedure for determining the specific gravity by means of a hydrometer is perhaps most appropriate for quality assurance determinations in the shipyard and is as follows.

Obtain the following equipment: (1) a hydrometer, (2) a thermometer, (3) a water bath capable of maintaining a temperature of  $15.56 \pm 0.05$  C ( $60.0 \pm 0.1$  F), and (4) a clear glass hydrometer cylinder. The hydrometer cylinder shall have an inside diameter of at least 1 inch greater than the outside diameter of the hydrometer, and be of such height that when in use the hydrometer will be at least 1 inch from the bottom of the cylinder.

Cool the sample in the original container (or in a closed sample container) to approximately 14 C (57 F). Rinse each piece of equipment with a portion of the sample. Pour the sample into the hydrometer cylinder so as to avoid bubble formation. Place the cylinder in the water bath and gently stir the contents. When the temperature of the sample is 15.3 C (59.5 F), slowly lower the hydrometer into the sample to a level two smallest scale divisions below that at which it will float, and then release. When the temperature is 15.65 C (60.0 F) and the hydrometer is at rest away from the cylinder walls, determine the specific gravity by observing the surface of the liquid at such an angle that it becomes a straight line cutting the hydrometer scale.

---

Notes:

- (1) Specific gravity hydrometers are discussed in detail in F.T.M. Std. No. 141a-4183, 2.2.1 and shall conform to the essential requirements listed in Circular No. 16 of the National Bureau of Standards.
- (2) Thermometer. An ASTM gravity thermometer having a range of -20 to +102 C (-4 to 216 F) and conforming to the requirements for thermometer 12 C -49 is prescribed in ASTM E1.
- (3) A temperature of 15.56 C (60 F) is standard. However, if the product specific gravity is specified at another temperature, test at *that* temperature and use instruments calibrated and standardized at that temperature.

Refractive Index Reducing Solvents  
Method 2-19

Reference: ASTM Special Technical Publication 500 (Gardner/Sward)

Discussion

Because refractive index is very sensitive to differences in solvent composition, it can be very useful in determining product quality. The measurements can be made quickly and with the degree of precision necessary for routine examination. Several refractometers are available from the Fisher Scientific Company which will meet the needs of a quality assurance laboratory. The method of testing depends upon the instrument selected.



## APPENDIX II-A3

### QUICK TESTS FOR USE ON COATING FILMS

## APPENDIX II-A3

### QUICK TESTS FOR USE ON COATING FILMS

Method 3-1. *C o l o r*

Method 3-2. *Gloss*

Method 3-3. *Hardness"*

Method 3-4. Coating Thickness Measurement

(a) Wet Film

(b) Dry Film

Method 3-5. Adhesion

Method 3-6. Impact Resistance

Method 3-7. Abrasion Resistance

Method 3-8. Weldability (Preconstruction Primers" (Only)

Method 3-9. Coating Continuity

## II-A3-I

### Color Method 3-1

References: F.T.M. Std. No. 141a-4250; ASTM D-1729 and D-2244

Objective: To provide a method for the visual comparison of the color of a dried pigment organic coating with that of a color reference.

#### Procedure

The sample under test shall be applied to test panels in accordance with product specifications. Visually compare the color of the dried test film with that of the reference film (standard panel from-previously accepted lot) under an illumination substantially equal to that of a fairly light overcast northern sky. Exposed and wather coatings may be similarly compared with a specimen that has not been exposed.

Arrange the test panel and the color reference beside each other on a table in front of a north light so that the illumination centers on an angle of about 45 degrees and the viewing is nearly normal to the surface. Exclude adjacent colors from view by placing a piece of neutral paper with a square section cut from the center over the specimens, such that one-half of the square will be over the test panel and the other half over the color reference. If there is doubt about the color match, refer to alternate ASTM methods.

## II-A3-2

### Gloss Method 3-2

References: ASTM D-523-67 and F.T.M. Std. No. 141a-6101

Objective: To determine the specular gloss of nonmetallic organic coatings

#### Procedure

Coat and dry test panels with the material to be tested according to product specifications. Calibrate the 60-degree glossmeter\* at the start and completion of each test period on the working standard\*\* whose assigned value most nearly approximates the gloss of the specimen to be measured. Measure at least three portions of the specimen surface to obtain an indication of uniformity. Report the average specular gloss reading.

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\* A list of manufacturers of glossmeters can be obtained from ASTM Headquarters, 1916 Race Street, Philadelphia, Pennsylvania 19103.

\*\* Gloss standards are available from the Gardner Laboratory, P. O. Box 5728, Bethesda, Maryland 20014, and the Hunter Associates Laboratory, 9529 Lee Highway, Fairfax, Virginia 22030.



## II-A3-3

### Pencil Hardness

#### Method 3-3

References: Paint Testing Manual, Gardner/Sward  
ASTM Special Technical Publication 5C10, 5.1.2.16

Objective: To rate the relative hardness of an organic finish according to the hardness of a lead pencil that will penetrate the surface.

#### Procedure

Apply the coating to test panels and allow to dry for specified time. Use a set of pencils\* obtained from one manufacturer, ranging from the hardest, 9H, to the softest, 6B, pencil. Prepare the pencils by carefully removing the wood from the lead for a distance of approximately 1/4 inch without chipping the lead. Square the end of the exposed lead by a gentle rotary motion against No. 400 carbide abrasive papers. Select a pencil and hold it at approximately 45 degrees to the paint surface; push forward against the surface using pressure short of breaking the lead. The finish is considered to have failed when a pencil removes chips, flakes, scales, or shears the finish from the substrate. Repeat the test several times on different areas of the test panel to determine reproducibility. Report the hardness as the grade of the next softer pencil.

---

\* The pencils referred to are standard drafting pencils. They are available from most drafting and engineering material dealers. One supplier is:  
J. S. Stoedtler, Inc., Department 66, P. O. Box 68, Montville, New Jersey 07045.

Coating Thickness Measurements  
Method 3-4

(a) Wet Film Thickness

References: ASTM D-1212-54 and ASTM Special Technical Publication 500  
(Gardner/Sward)

Objective: To measure the wet film thickness of paints and related products.

Inmont Wet Film Gage

An "Inmont Wet Film Gage"\* is a recommended procedure for measuring wet film thickness of marine paints. The gage is essentially a pair of wheels and a ring of shorter radius mounted eccentrically between them so that on one radius. the wheels and the ring are tangent. Two symmetrical scales on one face of the gage show the clearance of the ring at any point on the circumference.

Place the gage on the wet film so that the smallest reading is at the top. Roll the gage over the film one-half revolution toward the minimum marking on the gage. The thickness is read at the point a: which the paint makes contact with the eccentric wheel.

Tooth Gage

The tooth gage is a small square or rectangle c: metal with "teeth" of graduated clearances cut in the edges. Measurements are made by placing the gage against the painted surface in firm contact with the substrate, then withdrawing the gage and noting which teeth have been wet by the film.

By design, these gages measure the thickness of the coating above the peaks on a blasted surface. If calculations are to be made of the amount of primer to be purchased to produce a given wet film measurement on a rough surface, allowance must be made for the material that will be adsorbed into the surface irregularities. This cannot be measured accurately but can be estimated if degree of roughness is known.

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\* This gage is available from Gardner Laboratory, Inc., Bethesda, Maryland.

(b) Dry Film Thickness

General Discussion

Measurement of dry film thickness of **paints** over rough surfaces continues to be a problem for the reasons discussed below.

Magnetic gages are most practical of the various methods for use in the shipyard. The common gages fall into two types:

- (1) Pull-off gages which measure force required to pull a magnet from the paint surface. Common gages of this type include
  - (a) Mikrotest - Elektro Physik (Cologne)
  - (b) Tinsley Pencil Gage - Evershed & Vignoles (London)
  - (c) Elcometer Pull-Off Gage - Elcometer Instruments, Ltd.
  - (d) Inspector - Elcometer Instruments, Ltd.
- (2) Gages that measure changes in magnetic flux within the probe or instrument itself, such as
  - (a) General Electric Type B Thickness Gage
  - (b) Elcometer
  - (c) Minitector - Elcometer Instruments, Ltd.

With these instruments, the proximity of the steel substrate to the probe or contact point of the gage affects either, (1) the force of attraction between the magnet and the steel substrate (pull off gage) or (2) the magnetic flux within the gage (*gages* based on magnetic flux). The gages actually measure space between the probe and the magnetic surface of the steel. If the steel under the coating is smooth and free of contamination such as scale, the reading is actually the coating thickness. However, if scale or rust is present, the instrument measures that thickness along with the thickness of the paint film.

The situation is further complicated on rough (blasted) surfaces. In this case, the magnetic surface seen by the instrument fails somewhere within the transition zone; between the deepest valley and the highest peak.

Film Thickness Measure-  
ments in Laboratory

For laboratory use in the shipyard, the General Electric\* or similar gage is suggested for ease of use and accuracy. This is one of several gages which use magnetic flux to determine proximity to a ferrous substrate. It consists of a probe, electrically connected to a control unit which is connected to a power supply. The meter of the control unit indicates thickness in mils.

To standardize the instrument, place the standard shim (usually supplied with the instrument) on an uncoated smooth steel surface, and with the instrument probe on the shim, calibrate the instrument. Coating thickness can then be measured by placing the probe on the surface and noting the reading on the meter. Shim stock should be approximately equal to thickness of coating to be measured.

The Magne-gage\*\* is another useful instrument for laboratory measurements. Its use is covered by F.T.M. Std. No. 141a-6181 and ASTM D-1186.

The apparatus consists of a small bar magnet freely suspended from a horizontal lever arm. The latter is actuated by a spiral spring which is coiled by turning a graduated dial.

The instrument shall be firmly positioned on a level table or bench and calibrated with the reference thickness standard supplied with the instrument. To measure coating thickness, center the test panel under the plastic magnet guard and lower the carriage until the magnet guard rests gently on the panel. Slowly rotate the dial counterclockwise until the stop is reached, bringing the magnet in contact with the panel. Now rotate the dial clockwise with a slow, uniform movement until the magnet is detached. The attractive force between the magnet and the film substrate is indicated on the dial, and the film thickness is obtained from a calibration curve relating thickness to dial readings.

Film Thickness Measure-  
ments in Shipyard

For use out in the shipyard at the paint application site, less cumbersome gages are desirable. Any one of the following can be used:

- |                        |                         |
|------------------------|-------------------------|
| (1) Elcometer          | (3) Minitector          |
| (2) Elcometer Pull-Off | (4) Tinsley Pencil Gage |

This and other similar gages are available from Gardner Laboratory, Inc., Bethesda, Maryland.

The Magne-gage is available from the American Instrument Company.

Adhesion  
Method 3-5

References: ASTM D-2197-68 and F.T.M. Std. No. 141a-6303.1

Objective: To determine the "scrape" adhesion of organic coatings such as paint, varnish, and lacquer when applied to smooth, flat panel surfaces.

Procedure

Several methods are available for obtaining indication of adhesion or bonding of a coating, but none are completely satisfactory. One method is to use a balanced-beam scrape-adhesion tester\*. The apparatus shall consist of a balanced beam to which is secured a platform for supporting the weights, and a rod at an angle of 45 degrees which holds the scraping loop. Apply and dry the coatings to be tested on steel panels according to product specifications. It should be noted that roughness of the panel will make this test difficult to perform, so it may be desirable to apply the coating to a relatively smooth surface.

Either mask the panel or remove material after application, so that 1/2 inch at one end of the panel is uncoated. Position the apparatus so that the weight holder is pointing toward the operator; then level the base plate. Raise the beam and place the test panel on the sliding platform so that the specimen may be moved away from the operator and the uncoated portion is toward the main beam support. Select a weight and place it on the support and carefully lower the loop onto the uncoated portion of the test panel. Slowly push the sliding platform away from the operator for a distance of at least 3 inches. Continue testing on different areas until the minimum load necessary to remove the coating is determined. This load is considered to be the adhesion end point.

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\* The tester is available from Gardner Laboratory, Inc., Bethesda, Maryland.

## II-A3-8

### Adhesion (Subjective Test)

Reference: ASTM Special Technical Publication 500 (Gardner/Sward)

Objective: To determine the relative adhesion or bonding of an organic coating to a rigid substrate by a "cross hatch" adhesion test.

#### Procedure

Coat and dry the material to be tested on steel test panels according to product specifications. Place the test panel on a rigid table and with a sharp instrument make eleven parallel cuts through the coating in one direction and a second series at right angles to the first; this will form 100 squares. A device for doing this can be constructed from single-edge razor blades clamped together (with spacers) in a special holder which must be made for this purpose. The cuts should be uniformly apart, usually from 1/32 to 1/16 inch. Firmly place adhesive tape over the "cross hatch" area. Remove the tape with one quick motion and examine the area for coating removal. Retain the tape elsewhere on the panel for future reference. An estimate of adhesive failure may be made by determining percentage of film removal. This test is generally easier to perform on thinner coatings in the range of 2 to 3 mils than on the thicker, 6 to 8-mil coatings.

### Adhesion "(Subjective Test)

Reference: F.T.M. Std. No. 141a-6304.1

Objective: To test a paint film for adhesion, brittleness, toughness, and tendency to ribbon with a knife.

#### Procedure

Apply and dry the coating to be tested as specified in the product specification. Test for adhesion, brittleness, toughness, and tendency to ribbon by cutting a narrow ribbon of the coating from the test panel with a standard knife\* while holding the blade at an angle of approximately 30 degrees to the panel. This test should be performed only by someone of long experience in testing coatings of a similar nature, and is most useful when direct comparisons are made between unknown and known coatings.

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\*A craftsman's knife with a curved blade such as is illustrated in the Stores Stock Catalog, Federal Supply Service, as Item 5110-596-8098.

Impact Resistance  
Method 3-6

Reference: ASTM D-2794-69

Objective: 70 determine the ability of a coating to resist shattering, cracking, or chipping when the film and surface are subjected to impact.

Procedure

Prepare and coat test panels in accordance with product specifications. Place the test panel in the impact tester\* with the coated side up. Raise the weight up the tube to a height where it is expected that no failure will occur. Release the weight so that it drops onto the indenter. Remove the test panel and observe the impact area for cracks in the coating. "If no cracks are evident, repeat the procedure on different spots at increasingly greater heights until visible cracks are observed. Report the maximum number of inch-pounds withstood by the coating without evidence of cracking.

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\*Impact tester. Available from Gardner Laboratory, Inc., P. O. Box 5728, Bethesda, Maryland 20014. The apparatus consists of the following:  
a vertically mounted guide tube with calibration marks and a slot cut lengthwise on one side, a cylindrical weight made to fit inside the tube, and an indenter mounted on a steel block beneath the weight. A pin is fitted to the weight through the slot in the guide tube and is used to raise and release the weight.

Abrasion Resistance  
Method 3-7

References: F.T.M. Std. No. 141a-6191, 6192, and 6793  
ASTM D-968-51 and D-658-44

Falling Sand Method

Objective: To determine the resistance of organic coating to abrasion by falling sand.

Procedure

This test shall be performed with a falling sand abrasion tester\* which consists primarily of a funnel for loading sand, a vertical guide tube, a 45-degree test panel mount, and a sand collector. The apparatus shall be adjusted so that the inner concentrated core of sand falling from the lower end of the guide tube falls in the center of the flow. The efflux time for 2 liters of sand shall be  $22 \pm 1$  second.

The coating to be tested shall be applied to clean steel panels at a uniform thickness according to product specifications. After proper curing, the coated panel shall be secured in the tester. Standard sand, measured volumetrically in a graduate, shall be poured into the funnel until a 5/32-inch diameter area of the base panel is exposed. The thickness of the coating around the wear pattern shall be determined. At least three determinations shall be made on each panel. Calculate the abrasion coefficient as follows:

$$\text{Abrasion Coefficient, liters per mil} = \frac{V}{T}$$

where

V = volume of sand used in liters, and  
T = thickness of coating in mils.

Report the abrasion coefficient as the average value for the three determinations.

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\* An abrasion tester meeting the necessary requirements is available from Gardner Laboratory, Inc., P. O. Box 5728, Bethesda, Maryland 20014.

\*\* Standard sand meeting test requirements may be obtained from the Ottawa Silica Company, Ottawa, Illinois.



Taber Abraser

Objective: To determine the abrasion resistance of films of organic coatings using the Taber Abraser\*.

Procedure

The apparatus shall consist of a Taber Abraser; it is essentially an apparatus .with a turntable on which test panels are mounted, then abraded with abrasive wheels under a specified load.

Apply the coating to be tested on several 4 x 4-inch steel test plates with 1/4-inch center holes. Dry or cure the coating according to product specifications. Weigh the test specimens to the nearest 0.1 milligram and record their respective weights. Measure the thickness of each test film along the path to be abraded and record the results. Mount the abrasive wheels and adjust the loading to the specified wheel pressure. Fasten the specimen on the turntable and lower the abrading heads carefully onto the test film. Place the vacuum pickup nozzle in position and start vacuum pickup. Start the abraser motor and continue the abrasion until the specified number of wear cycles have been completed or the film has worn through to the substrate. Record the number of wear cycles and repeat the operation on each of the remaining test specimens. Report the average result by whichever of the following ways is required in the product specification:

Wear Index. Calculate the weight lost in milligrams per 1,000 - cycles of abrasion.

Wear Cycles. Determine the number of cycles of abrasion required to wear the film of specified thickness through to the test plate.

The Spinning Disk: Seawater-Sand Slurry Test is another method for measuring abrasion resistance of coatings, and is especially useful for bottom coatings and boottop paints. It is described in Method 4-15 in Appendix 11-A4.

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\* An abrasion tester meeting the necessary requirements is available from Gardner Laboratory, Inc., P. O. Box 5728, Bethesda, Maryland 20014.

Test for Weldability  
Method 3-8

Reference: There is no applicable specification.  
Some advice is given in report(o)

The fillet weld test customarily used to evaluate weld quality can also be used to examine the effect of the primer on weldability. This test consists of welding simultaneously both sides of a fillet over a minimum length of 10 inches. A visual inspection of porosity, contour, size, and possible undercut is made. The fillet is then broken open so that the weld interior can be inspected. The fractured surface should be free from harmful defects such as cracks, lack of fusion, or unacceptably high porosity. This test should be conducted under welding conditions and procedures identical to those of interest to the shipyard so that the results will be meaningful.

Coating Continuity  
Method 3-9

Coating continuity (absence of voids, pinholes, etc.) can be checked with a high-frequency spark tester (jeep test). One instrument of this type is the UVRAL\* Spark Tester. It is available with a number of probes including a brush-type detector. Where there are voids in the coating, a spark will jump from the detector to the metal, and an alarm will sound.

Another technique is to use an Elcometer Pin Hole Detector\*. This instrument is most effective when used on coatings of thicknesses up to 12 mils. The handle of the instrument houses a 9-volt battery at one end and a solid state circuit at the other. The metal rod probe has a sponge attached at the end. When water from the sponge penetrates a void in the coating, contact is made with the metal substrates which completes a circuit and produces a signal. Because voltage is low there is no damage to the coating.

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\* Distributed by Allen P. Webb, 24 Stone Street, New York City.



**APPENDIX II-A4**

PROLONGED AND SIMULATED SERVICE  
TESTING OF COATING FILMS

## APPENDIX 11-A4

### PROLONGED AND SIMULATED SERVICE TESTING OF COATING FILMS

- Method 4-1. Outdoor Exposure - Atmospheric
- Method 4-2. Accelerated Weathering - Weather-Ometer
- Method 4-3. Salt Fog Exposure
- Method 4-4. Cyclic Testing. Accelerated Weathering - Salt Fog Exposure
- Method 4-5. Cleveland Condensing Cabinet
- Method 4-6. Cyclic Testing. Cleveland Condensing Cabinet - Freezing
- Method 4-7. Simulated Seawater Immersion (Laboratory Tanks)
- Method 4-8. Seawater Immersion - Raft Tests
- Method 4-9. Discontinuous Seawater Immersion
- Method 4-10. Seawater Immersion Moving Panels (Rotors)
- Method 4-11. Synthetic Seawater Immersion of Panels in a Hydrodynamic Double Chambered Tank.
- Method 4-12. Patch Tests on Ships
- Method 4-13. Test Panels Attached to Ships
- Method 4-14. Immersion Testing Ship Tank Linings
- Method 4-15. Seawater Immersion Under Cathodic Protection
- Method 4-16. Spinning Disk: Seawater - Sand Slurry

## II-A4-1

### Outdoor Exposure - Atmospheric Method 4-1

Reference: F.T.M. Std. No. 141a-6160 or ASTM D-1014

Objective: To determine relative service of exterior paints when applied to metals exposed outdoors in a marine environment.

#### Procedure

The specifications should be used as guides. The base metal used for test specimens is to be of hot-rolled steel comparable to ship plate. The preparation of test specimens is described elsewhere in the Appendix. The paint shall be applied by the procedure commensurate with the manufacturer's suggestions and the yard practices. The specimens shall be mounted in an exposure rack so that none contact each other, or cast shadows on others. Run-off from panels should not flow over others. It is suggested that the racks be in a marine environment, preferably very near salt water with panels facing south. The panel holders should insulate the panels from the rack and from each other, and not damage the panels. Angle of exposure can fit the individual needs of the yard, but if only one exposure angle is used, the angle suggested is 45 degrees.

The shipyard may find it more convenient to expose panels at a commercial exposure site rather than carry out the exposures in the yard.

The panels should be examined periodically (some prefer monthly inspections while others use less frequent examination). The panels should be graded for the following:

Corrosion - Method 5-1 (Appendix 11-A5)

Adhesion - Method 5-2 (usually only at end of test)

General Appearance - Method 5-30

## II-A4-2

### Accelerated Weathering Method 4-2

References: F.T.M. Std. No. 141a-6152  
ASTM E-42-65 (Carbon-Arc Type)  
ASTM E-239-64T (Water-Cooled Xenon-Arc Type)

Objective: To expose coatings to UV light and water spray to give early (accelerated) indication of potential performance outdoors.

#### Procedure:

The specifications are to be used as guides, but the shipyard may select the type weathering device and exposure cycle to fit individual conveniences. The Weather-Ometers <sup>(R)</sup> are available in several models. Each operates on the principle of exposing coatings to intense UV light with cycles of water spray. A popular cycle for the twin-arc type is 102 minutes of UV light only and 18 minutes of light and water spray. A xenon-arc model has the advantage of more continuous operation without the maintenance required in the twin arc, which requires changing the carbon electrodes each day. A humidity-controlled Sunshine model has the advantage of cycles which include darkness with a chilled water spray on the backs of panels to cause condensation on the coating. This model produces more rapid failure in many coatings than is caused by the other models.

Accelerated weathering results cannot be correlated directly with length of service outdoors. Nevertheless, the test provides an excellent method for judging relative merits of different coatings. Therefore, control coatings of known performance should always be exposed at the same time as the new and unproven coatings.

At various periods of exposure (usually each 100 hours) the panels are graded for the following:

Corrosion - Method 5-1 (Appendix 11-A5)

Adhesion - Method 5-2 (usually only at end of test)

General Appearance - Method 5-3.

---

\* Atlas Electric Devices Company, 4114 N. Ravenswood Avenue, Chicago, Illinois 60613.



## II-A4-3

### Salt Fog Exposure Method 4-3

References: ASTM D-117-64 and F.T.M. Std. No. 141a-6061

Objective: To help appraise performance potential of marine coatings.

#### Conditions

A detailed description of standard salt-spray cabinet requirements is given in the ASTM designation D-117-64. The cabinet\* consists essentially of the following: a fog chamber, a salt solution reservoir, a supply of suitably conditioned compressed air, one or more atomizing nozzles, specimen supports, and provision for heating the chamber. The following operating requirements are to be met:

- (a) Salt solution. The salt solution shall be prepared by dissolving 5 parts by weight of sodium chloride in 95 parts of distilled water or water containing not more than 200 ppm of total solids. The pH of the solution shall be such that when atomized at 95 F the collected sample will have a pH of 6.5 to 7.2.
- (b) Air supply. The air supply for atomizing the salt solution shall be free of dirt and oil and maintained between 10 and 25 psi. In addition, the air shall be so humidified that upon release into the chamber it will have a relative humidity between 95 and 98 percent.
- (c) Temperature. The exposure zone of the cabinet shall be maintained at 95 F plus 2 or minus 3 F. Record the temperature of the exposure zone at least twice a day at approximately a 7-hour interval.
- (d) Quantity of fog. Two or more fog collectors shall be placed within the exposure zone in the proximity of the test specimens. The fog shall be such that for each 80 cm<sup>2</sup> of horizontal collection area there will be collected from 1.0 to 2.0 ml of salt solution per hour when based on a 16-hour run.

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\* Salt Fog Cabinets are available through Gardner Laboratory, Inc., Bethesda, Maryland.

## II-A4-4

- (e) Position of specimen. The specimens shall be supported with the dominant test surface between 15 and 30 degrees from the vertical. Arrange the specimens so that they do not contact each other or any metallic material or any material capable of acting as a wick. Condensate shall not fall from one specimen upon another.

Since position of the panel within the cabinet can have effect on test results, it is suggested that at least two specimens be exposed; *in* different positions within the cabinet. A control coating of known performance potential should always be exposed alongside the unknown coatings for direct comparison.

## II-A4-5

### Cyclic Testing Accelerated Weathering - Salt Fog Method 4-4

References: Method 4-2, Accelerated Weathering, and  
Method 4-3, .Salt Fog Exposure.

A valuable laboratory test procedure for marine paints used above the waterline is alternate exposure to accelerated weathering and salt fog. There is no standard time cycle for these exposures. However, Newfield, et al(1) found that alternate exposure to Weather-Ometer and Salt Fog was a promising accelerated screening test, and that a cycle of 20 hours Weather-tieter (Twin Arc) and 4 hours salt fog was most accelerated of the cycles tried. Whatever cycle is chosen, it will probably be expedient to examine the test specimens at the end of each cycle. The panels are to be examined according to Methods 5-1, 5-2, and 5-3 (Appendix 11-A5).

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(1) Reference 264, Appendix III -A.

Cleveland Condensing Cabinet  
Method 4-5

Reference: Publications (1) by the Cleveland Society for Paint Technology

The Cleveland Condensing Cabinet<sup>(2)</sup> is designed to expose test panels to 100 percent humidity with continuous condensation on the coated face of the test panel. The coated panels are laid in racks at the top of the cabinet. The backs of the panels are exposed to ambient (room) temperature. The temperature of the water in the pan below the test specimens can be varied up to 180 F. A suggested operating procedure is to maintain the water at 120 F and the ambient (room) temperature at about 72 F.

The continuous water condensation can cause more rapid blistering of a marine coating than is experienced with continuous saltwater immersion. Thus, the Cleveland Cabinet can be used for accelerated testing of marine coatings. The coatings of unknown potential should be exposed alongside coatings of known performance. In this way judgment of the relative merits of the unknown coatings can be made even though the time-to-failure in the test cannot be correlated directly with actual service life in the marine environment.

Panels should be examined daily for the first week and twice weekly thereafter until failure occurs by blistering, peeling, or corrosion. Panels should be examined as follows:

- (a) Corrosion - Method 5-1 (Appendix 11-A5)
- (b) Adhesion - Method 5-2 (usually only at end of test)
- (c) General Appearance - Method 3-5.

---

(1) Official Digest, Dec. 1963, ~ (467), p 1318-1.327.  
Official Digest, Nov. 1965, 37 (490)

(2) Manufactured by Q-Panel Company, 15610 Industrial Parkway, Cleveland, Ohio 44135.

## II-4-7

### Cyclic Testing Cleveland Condensing Cabinet - Freezing Method 4-6

A cyclic test can be conducted using a procedure similar to that described in Method 4-5, except that the test panel is exposed 22 hours on the Cleveland Condensing Cabinet followed by 1 hour in a freezer at 0 to 10 F and then 1 hour at room temperature. The cycle is repeated until visual failure occurs. Examination should be made as follows:

Corrosion - Method 5,1 (Appendix 11-A5)

General Appearance - Method 5-3

Adhesion (at end of test period) - Method 5-2.

Simulated Seawater Immersion  
(Laboratory Tanks)  
Method 4-7

Test panels should be prepared as described in Method 6-1. Simulated seawater should be prepared as described in Method 6-8.

Corrosion-resistant laboratory tanks should be constructed large enough to hold a number of the 6 x 12-inch test panels spaced at least 1 inch apart (distance between panel faces). A convenient tank size is about 12 x 12 x 30 inches, which is the approximate size of an elongated 20-gallon, glass aquarium available from some hobby stores.

The panels should be supported from a rod placed above the tank, using insulated, nonmetallic hangers. The tank should be filled to a convenient level with synthetic seawater.

Bubbling of air through the water will produce a more corrosive environment. However, care must be exercised to distribute the air uniformly between the faces of the test panels. This can be done by laying a plastic tube along the bottom of the tank with very small holes in the tube spaced at the same interval as the distance between panels. The tube can be connected to any convenient source of compressed air.

The photograph in Figure 4 shows a typical seawater immersion test setup similar to that described above.

The panels immersed in synthetic seawater should be examined at suitable intervals, usually no less frequently than once per month. The panels should be rated as described in Test Methods 5-1, 5-2, and 5-3.

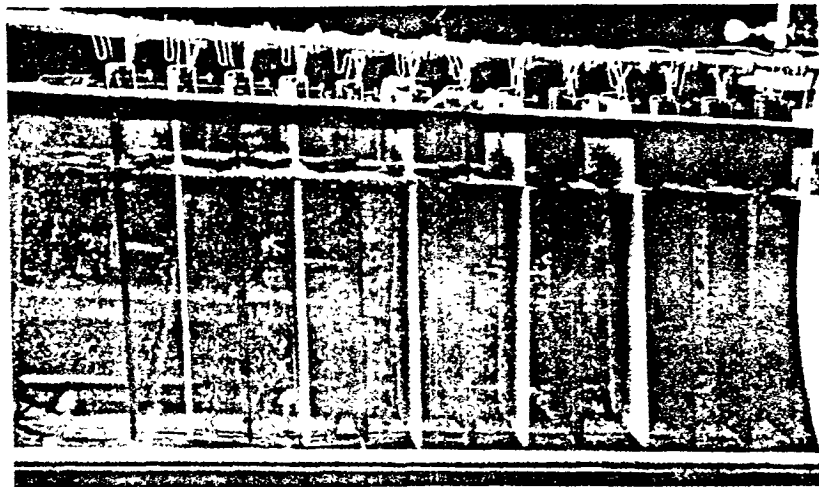


FIGURE 4. SIMULATED SEAWATER IMMERSION  
 TESTING IN LABORATORY

Seawater Immersion - Raft Tests  
Method 4-8

'Seawater immersion of test panels suspended from rafts has been used for many years as a method to evaluate boottop and ship bottom paints, including antifouling coatings. There is no standard procedure for carrying out these tests and techniques vary from one exposure station to another. Some suspend panels from floating rafts so that depth of panel is always the same regardless of tide. Others suspend panels from piers in such a way that depth varies with tide. In some cases, the panels are suspended from piers so that all or part of the panel is above water at low tides and the panel is entirely under water at high tide. This method may be used for boottop paints.

The place selected for seawater immersion tests is very important. There should be a good continuity of marine fouling organisms present, including both hard fouling and grasses. The area should also be protected from storms and wave action; for examples an inlet or sheltered harbor area. The following description of procedures is offered as a guide:

The raft or dock should be constructed with walkways separating open areas where the test panel racks can be suspended. The racks may be constructed from wood and protected with a high-quality antifouling paint. The racks should be of such size as to hold six or eight of the 6 x 12-inch steel panels described in Method 6-1, Preparation of Test Panels. The racks can be suspended from the dock by suitable lines, such as nylon.

Inspections of panels should be on a monthly basis. The panels should be examined for protective properties and film defects, using Method 5-1 and 5-3 as a guide. They should also be rated for fouling according to Method 6-10. When noticeable changes occur, it is very helpful to take color photographs to retain as records of condition.

The photograph in Figure 5 shows an exposure dock at a marine exposure site. The photograph in Figure 6 shows a test rack removed from the water for examination of test panels.

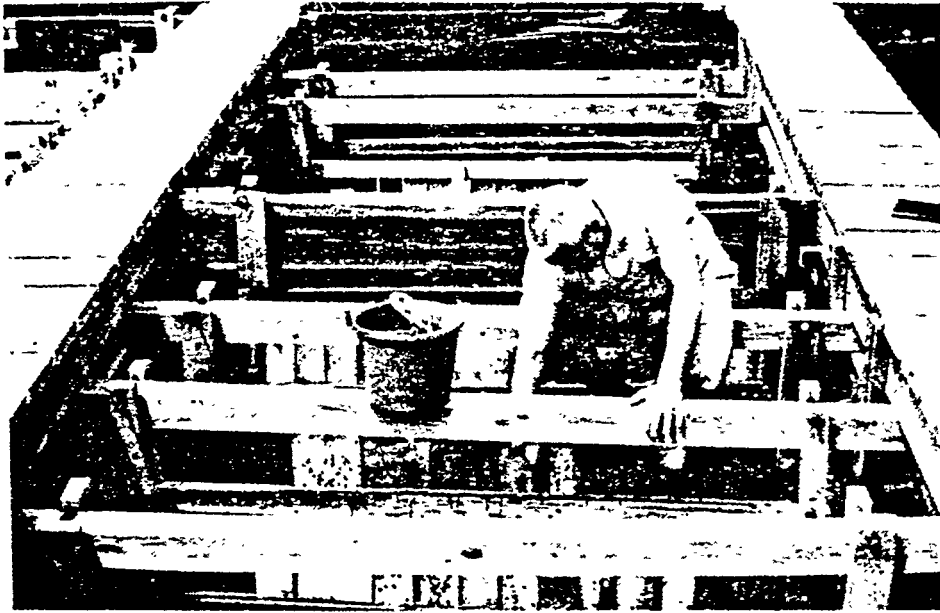


FIGURE 5. MARINE EXPOSURE DOCK

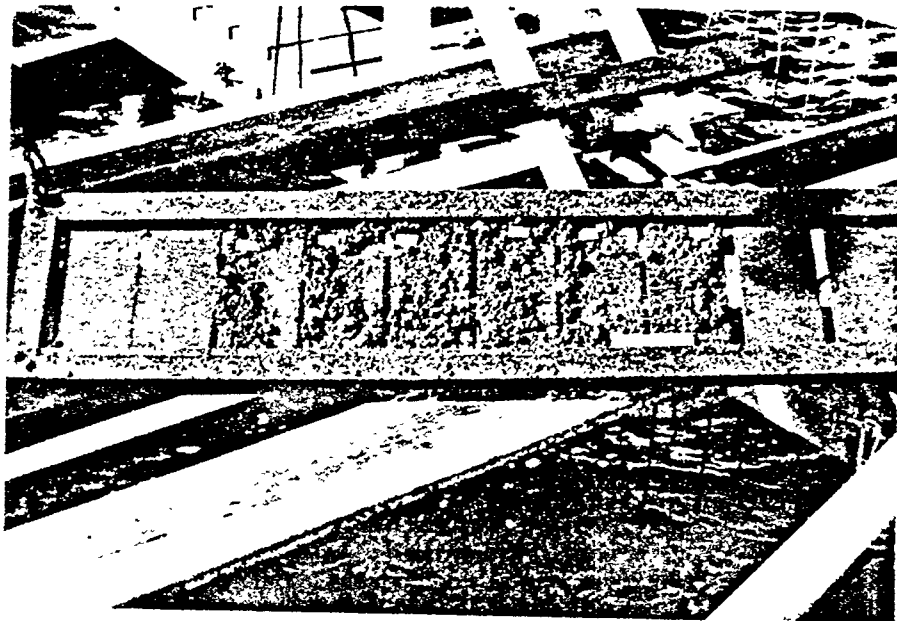


FIGURE 6. TEST RACK REMOVED FROM  
SEAWATER FOR EXAMINATION



Discontinuous Seawater Immersion  
Method 4-9

Discontinuous Seawater Immersion is useful for testing boottop paints. The alternate wetting and drying of Some paints, along with part-time exposure to sunlight can be much more destructive than continuous immersion.

The panels maybe immersed as described in Method 4-8. Periodically, they should be lifted from the water and the rack suspended in air and facing south so that sunlight may strike the faces of the panels. There is no standard time cycle for doing this. However, a suggested schedule is 11 days immersion followed by 3 days above water. The panels should be examined on a monthly basis using the following methods as a guide: Methods 5-1, 5-3, and 6-10..

Seawater Immersion Moving Panels (Rotors)  
Method 4-10

There are advantages in testing boottop and ship bottom paints in motion to simulate ship movement. The rapid flow of water over a paint surface produces differences in coatings deterioration, and especially more rapid loss of toxicant than from antifouling paints tested stationary. The test should be made with panels under motion part of the time and stationary part of the time to allow attachment of marine fouling. There is no standard cycle established, but a suggested procedure is 2 months in motion and 1 month stationary.

titers are difficult to operate and expensive to maintain. Therefore, the shipyard may prefer to use rotors available at various marine exposure stations. The following stations are now operating rotors, or have operated rotors in the past:

- (1) Ocean City Research Corporation, Ocean City, New Jersey
- (2) Miami Research Inc., Miami, Florida
- (3) Florida Marine Research Facility of Battelle-Columbus Laboratories, Daytona Beach, Florida.

The following schematic of a rotary wheel is for one used at F.M.R.F.:

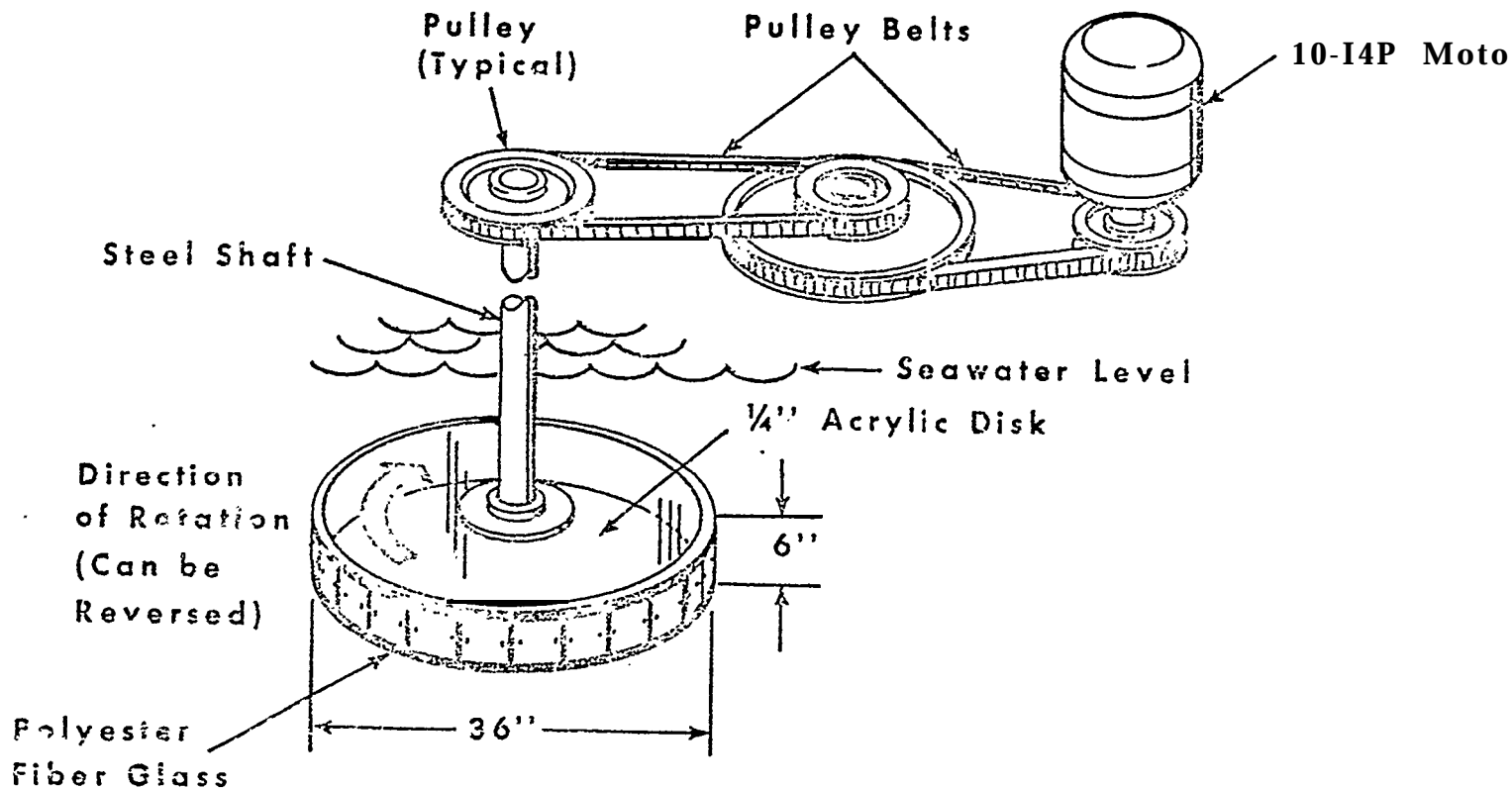


FIGURE 7. SCHEMATIC OF ROTOR APPARATUS

## II-A4-13

Each rotary wheel is essentially a 6-inch segment of a 36-inch-diameter cylinder mounted on a vertical shaft **so that the outer** circumference of the wheel is a vertical surface, to which eighteen 6 x 6-inch panels can be mounted.

The cylinder segment is polyester fiber glass and is mounted onto the center steel shaft by means of a 1/4-inch acrylic plastic disk. The center shaft is connected to a 10-hp electric motor through a pulley-belt assembly which reduces the 1760 rpm speed of the motor to approximately 200 rpm for the wheel. Two speeds are currently being used: 18 knots and 22 knots. The 6 x 6-inch steel panels are preformed to a 36-inch-diameter radius of curvature and are mounted on the wheel by means of two nylon bolts.

Panels exposed on the rotor should be examined monthly using the following as a guide: Method 5-1, 5-3, and 6-10.

Synthetic Seawater Immersion of Panels in a Hydrodynamic  
Double Chambered Tank.  
Method 4-11

For testing top coat compatibility of different primers with different top coat systems as well as for testing boottop and ship bottom paint systems hydrodynamic conditions are important.

The test panels are secured in the upper portion of the double chambered tank. The tank can be filled with fresh water or synthetic sea water. The water is circulated at approximately 18 knots.

A double chambered tank was built under the Maritime Administration Project SF 1-6 "Improved Fabrication Primer for Protection of Steel". It is operated at Avondale Shipyards, Inc., Avondale, LA.

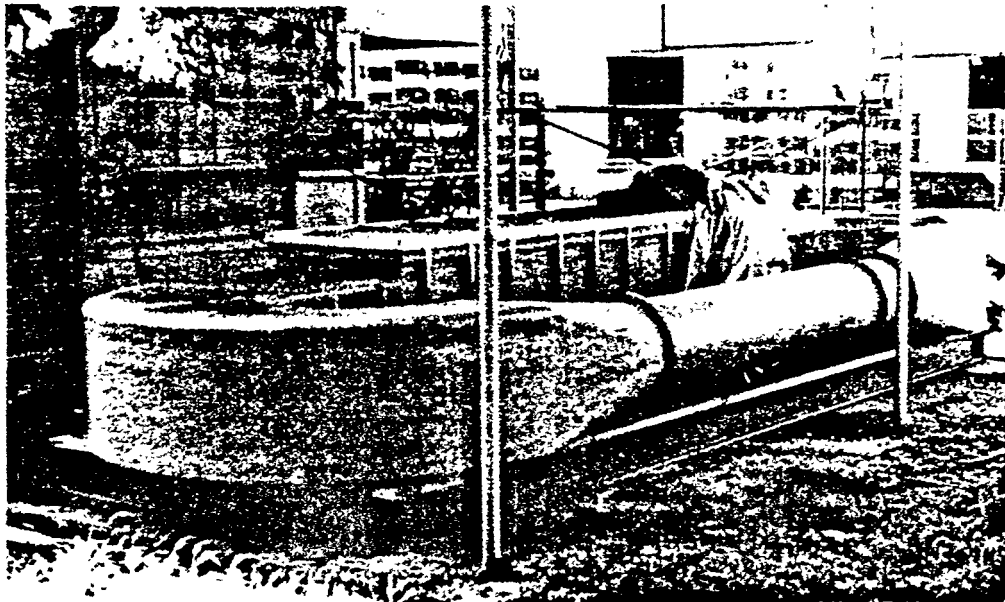


FIGURE 7A, HYDRODYNAMIC DOUBLE  
CHAMBERED TANK

Patch Tests on Ships  
Method 4-12

Patch tests on ships are an effective way to evaluate coatings under actual service conditions. However, examination of bottom coatings may be difficult and much valuable information may be lost if examinations of the paints cannot be made at the proper times. Patch tests topside may be undesirable because of differences in appearance of the paints under examination. However, topside paints can be placed where they will be easy to examine.

When comparing different paints by patch tests, great care must be taken to assure that each paint is subjected to the same conditions. This can be done with bottom paints by dividing the bottom area into quarters with one paint applied portside forward and starboard aft, and the other starboard forward and portside aft. If patches of several paints are to be tested on the same ship, it is wise to test each paint in more than one location, and plan the patch tests to *subject each paint to as similar conditions as possible*.

The paints should be examined using the following as a guide:  
Methods 5-1, 5-3, and 6-10.

Test Panels Attached to Ships  
Method 4-13

Test panels may be prepared as described in Method 6-1. The coated panels can then be attached to ships for exposure under actual service conditions. Generally, this procedure has been Used for ship bottom paints, but could be used for other-kinds of paints, with panels exposed at the appropriate locations on the ship. A convenient place to attach panels for testing ship bottom paints is at the bilge keel.

After exposure, the panel should be examined using the following as a guide: Methods 5-1, 5-3, and 6-10.

## II-A4-17

### Immersion Testing Ship-Tank Linings Method 4-14

Reference: Military Specification MIL-P-23236 (Ships)

Test Panels **may** be prepared as described in Method 6-1. The coated panels shall be subjected to 20 cycles (or to prior failure) with each cycle made up of the following four operations:

- (1) Immersion in salt water for one week at a temperature of 80 F + 10 F. The salt solution contains 3.0 percent of common table salt dissolved in distilled water.
- (2) Immersion in aromatic fuel for one week at 80 F + 10 F (following the saltwater immersion). The aromatic synthetic gasoline "to be used for the test is a blend containing 60 volumes of aliphatic petroleum naphtha (TT-N-95), 20 volumes toluene (TT-T-548), 15 volumes xylene (TT-X-916), and 5 volumes benzene (W-L-231).
- (3) immersion in hot synthetic seawater for 2 hours at 175 F; to simulate tank cleaning.
- (4) Hot seawater spray for 10 seconds with water temperature at 175 F. Each panel is to be placed in a suitable closed container and opposite a 3/16-inch spray nozzle set at a distance of 2-1/2 feet from the panel face. The nozzle pressure should be 25 pounds per square inch.

The panels should be examined carefully-after the 20 cycles; Methods 5-1 and 5-3 are to be used as a guide. If coating is still satisfactory, wipe lightly with a soft cloth and fresh water, allow 48 hours to thoroughly dry, and recoat the central upper third of one side of each panel, masking the portion from the edge to 1/2 inch inward (to simulate patching). Allow one week drying time and complete the testing with five additional cycles as described above.

The effect of-the coating on fuel degradation shall be measured by comparison of test results obtained on fuel *in* contact with the coating system with unexposed fuel of the same age. The procedures are involved and are spelled out in MIL-P-23236 (Ships).

If other products are to be carried in the tanks, separate immersion tests should be carried out with each product. The tests should be at ambient temperature (75 to 80 F) and at 120 F (accelerated condition). The panels should be examined using Methods 5-1 and 5-3 as a guide. Product should be examined for change in color, odor, and other noticeable change. For critical products, analysis of purity should be made by a commercial *testing* laboratory.

## **II-A4-18**

If it is necessary to meet the requirements of Specification MIL-P-23236 (Ships) with a tank lining, the procedure spelled out in the specification should be followed to the letter.



Seawater Immersion Under  
Cathodic Protection  
Method 4-15

In cases where bottom coating systems are to be used in conjunction with cathodic protection, they should be tested in seawater under an applied potential. The test panels should be prepared as described in Method 6-1. However, before the panels are blasted and coated, a steel wire should be attached by welding. The coating should be applied part way up the wire. This wire can then serve both as a hanger and to attach the lead wire for applying the potential.

The panels can be immersed as described in Method 4-7. The bare portion of the hanger and lead wire, however, should not be immersed. A simplified schematic for applying the potential is shown below.

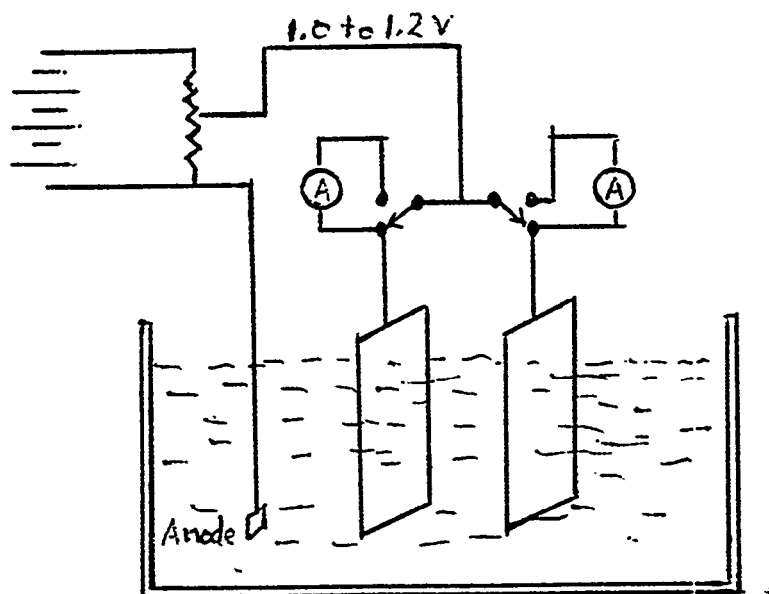


FIGURE 8. SCHEMATIC FOR APPLIED POTENTIAL TEST

Note: Transformers and rectifiers can be used as the source of D.C. potential instead of the batteries shown in Figure 8.

## II- A4-20

The panels under test should be examined periodically (at least *once* per month) according to Method 5-3. However, monitoring with a meter can give indication of early failure.

Spinning Disk:  
Seawater - Sand Slurry  
Method 4-16

The spinning disk method is used to determine relative resistance of various ship bottom and boottop paint systems to a rasion. The test is based on a procedure described by Orgonas and Delahunt<sup>(1)</sup>. The disk is attached to the end of a shaft which is turned by an electric motor, such as a drill-press motor. The carbon steel disks are 5 inches in diameter (other sizes up to about 12 inches could also be used, but adjustment in motor speed would be necessary to compensate). The disks are turned at a rotational speed needed to give a peripheral speed of 20 to 22 knots at the edge of the test panel. For a 5-inch-diameter wheel this would be about 1700 rpm.

The disk is to be coated with the paint to be tested following the manufacturer's specifications. The disk is immersed in a container of synthetic seawater (Method 6-8) and enough Ottawa sand added to maintain a sand level 1 inch above the disk. The panels are then spun for 1 hour.

Orgonas and Delahunt found that reproducible results could be obtained if two conditions were met:

- (1) Prior to testing, a bare steel disk be rotated for 1 hour in the sand-water slurry, and
- (2) Only 4 hours of testing be done before the sand is replaced, otherwise the sand loses its abrasive action.

The amount of wear back, or coating removal from the edge of the panel, gives indication of the abrasion resistance of the coating. The procedure is to be used only for comparing one coating with another because correlation with actual ship use has not been established.

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(1) Reference 307, Appendix III-A. "Protective Coatings for Hulls", R. R. Orgonas and J. F. Delahunt, Paint and Varnish production, 55, June, 1965, p 61-70.



**APPENDIX 11-A5**

**EXAMINATION OF COATINGS AFTER**  
**PROLONGED EXPOSURES**

## APPENDIX II-A5

### EXAMINATION OF COATINGS AFTER PROLONGED EXPOSURES

Method 5-1. Corrosion (Rusting)

Method 5-2. Adhesion Retention at End of Test  
(See Method 3-5 for measuring adhesion)

Method 5-3. General Appearance

- (a) Color (or Color Retention)  
(Use Method 3-1- Appendix 11-23)
- (b) Gloss (Use Method 3-2)
- (c) Blistering
- (d) Chalking
- (e) Checking
- (f) Cracking

## II- A5- 1

### Corrosion (Rusting) Method 5-1

References: ASTM D-610-68 and F.T.M. Std. No. 141a-6451

Objective: To evaluate the degree of rusting on painted steel surfaces.

#### Procedure

Black and white photographic reference standards are printed in each of the two references listed above. The numerical rust grade scales are based on an exponential function of the area of rust so that slight amounts of first rusting have the greatest effect on lowering the rust grade. Colored photographic reference standards are available at a nominal cost from ASTM Headquarters, 1916 Race Street, Philadelphia, Pennsylvania 19103.

## II-A5-2

### Adhesion Retention

#### Method 5-2

Refer to Method 3-5 for measuring adhesion after exposure and compare with the results obtained for the same coating system not exposed to the deteriorating environment.



## II-A5-3

### General Appearance After Exposure Method 5-3

#### (a) Color

Color retention is important for topside paints. Color after exposure should be compared with original color. See Method 3-1 for color measurement.

#### (b) Gloss

**Gloss** retention can be important for topside paints. See Method 3-2 for measuring gloss.

#### (c) Blistering

References: ASTM D-714-56 and F.T.M. Std. No. 141a-6461

Objective: To evaluate the degree of blistering on painted surfaces.

#### Procedure

Photographic reference standards "are printed in both of the above references. These reference standards represent the two characteristics of blistering: size of blister and frequency of blister. Four size grades are presented at four levels of frequency.

#### (d) Chalking

References: F.T.M. Std. No. 141a-6411 and ASTM D-559-44

Objective: To evaluate the degree of chalking of exterior paints.

#### Procedure

Chalking is that condition in paint films manifested by the presence of loose removable powder evolved from the film itself, at or just beneath the surface. The degree of chalking is determined by wrapping a wool felt (either black or white, determined for maximum contrast to the painted surface) around the index finger and with medium pressure to the film, stroke across the surface for a length of 4 inches. Repeat the test on an adjacent area of the felt and on a different area of the paint film. Compare the spots so obtained with the photographic reference standards printed in the above references. Record the number associated with the degree of chalking.

## II-A5-4

### (e) Checking

References: ASTM D-660-44 and F.T.M. Std. No. 141a-6421

Objective: To evaluate the degree of checking of exterior paints.

#### Procedure

Checking is that phenomenon manifested in paint films by slight breaks in the film that do not penetrate to the underlying surface. Photographic reference standards are printed in each of the above references. Compare the test surface under examination to the photographic references to determine the degree of checking. Record the number associated with the degree of checking.

### (f) Cracking

References: ASTM D-661-44 and F.T.M. Std. No. 141a-6471

Objective: To determine the degree of cracking of exterior paints.

#### Procedure

Cracking is that condition in paint films manifested by a break extending through the film to the substrate surface. The photographic reference standards printed in each of the above references are representative of degrees of cracking. The painted surface under examination is to be compared with the photographic references and the number of the reference matching the appearance of the painted surface recorded as the degree of cracking.



**APPENDIX 11-A6**

**MISCELLANEOUS PROCEDURES AND METHODS**

## II-A6-I

### Preparation of Test Panels Method 6-1

Reference: ASTM D-2200 - Preparation of Steel Panels

One type of steel panel having excellent merit for the testing of marine coatings is 6 x 12 inches in size, and cut from 1/8-inch-thick, hot-rolled stock similar to the steel used for ship plate. All edges of the panel should be rounded to provide easier coverage. The panels should be blasted to the same SSPC rating and surface profile normally obtained in the yard, but not less than a near-white metal rating; SSPC-SP 10-63 (unless effects of lesser treatments are under investigation).

Each part of each finishing system should be applied by spraying under carefully controlled conditions following exactly the procedures outlined by the coating supplier (or an applicable specification). Each part of the system should be applied to the thickness recommended using the number of spray coats specified; unless such is not compatible with yard procedures in which case the yard procedure will take precedence. Methods for measuring coating thickness are described elsewhere in this manual (Method 3-4). Drying time specified for the particular material will be allowed between coats, and after the last coat (before beginning the testing). Special care should be taken to assure that the back of each test panel is at least as well protected as the front. Edges must be well covered, so it is generally helpful to add additional top coat by dipping the edges into a shallow pan of coating material. This can be done as soon as the final spray coat is dry to touch.

In some testing it is desirable to observe coatings performance along scribe marks; to simulate coatings damage or incomplete coverage. The scribe marks may be made with any sharp blade or tool, except care must be taken to prevent chipping of the coating along the scribe marks.

Other size panels may be prepared as described above for various tests which require panels of specific size to fit the test apparatus. For accelerated weathering, panel size should be 3 x 9 inches to fit either the Sunshine or Xenon units or 2-3/4 x 5-7/8 inches to fit the Twin Arc machine. For the Cleveland Condensing Cabinet, the panels should be 4 x 8 inches.

Still other tests require a different kind of test panel having a smooth surface. Smooth panels are of advantage when testing relative adhesion of different coatings, and for Taber Abraser testing. Where smooth panels are desired, it will be convenient to use Q-Panels(R)\* because of their high degree of uniformity.

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\* Q-panel Company, 15610 Industrial Parkway, Cleveland, Ohio 44135.

Fading - Color Change  
Method 6-3

No applicable specification

Various resin binders and color pigments may be sensitive to uv light, and thus change in color and/or gloss during exposure indoors. To check the color and gloss stability of indoor paints, a simple procedure of indoor exposure in a room having only north lighting can be used. Panels prepared as described in Method 6-1 may be placed in racks suspended from the ceiling. The racks should be placed so that each panel being tested will receive about the same amount of light. Cover a portion of the panel with aluminum foil, and after a suitable exposure period of at least one year, remove the foil and compare visually the covered and uncovered areas of the panel.

## II-A6-2

### Coatings Application Over Damp or Contaminated Surfaces Method 6-2

This method is to be used when studying tolerance of coatings to moisture, and/or metal surface contamination. The procedure to be followed in panel preparation and coatings application is described in Method 6-1; with the exception of surface preparation. Instead, the test panel is to be pre-conditioned" to simulate the metal surface condition to be studied.

To evaluate coatings performance over rust, the panels may be allowed to rust simply by leaving them in a high-humidity area after blasting.

To evaluate coatings performance over surface moisture, the panels should be placed in a freezer, and then brought out for coating. Water can be allowed to condense on the surface before the paint is applied. The amount of condensation may be controlled to some extent through repeated trials of different time in the freezer.

The paint should be applied over the contaminated surface as described in Method 6-1.

## II-A6-5

### Fire Resistance - Flammability Method 6-5

Reference: ASTM D-1360 and D-1361

Objective: To compare flammability of different paints for living spaces in ships.

#### Procedure

Both **tests** are difficult to perform if the specifications are to be followed exactly. D-1360 is a cabinet method of fire testing, and D-1361 is a stick and wick method. The stick and wick method would be easier for the yard to use because it does not require construction of the special fire chamber.

The coating is applied to a 1 x 1 x 16-inch white sugar pine panel. A wick is made from a 6-inch length of gage compress by folding twice lengthwise. The wick is wrapped around the painted stick, wet with alcohol, and ignited. After 100 seconds, the flame is extinguished by carbon dioxide. Comparisons are made of flame spread, char, and weight loss between painted **sticks and** unpainted sticks. The **exact** procedure is described in ASTM D-1361.



Washability of Paints  
Method 6-4

Reference: F.T.M. Std. No. 141a, Method 6141

objective: To determine ease of removing soil from the surface of an interior paint.

Procedure

The specification should be used as a guide, but is perhaps too detailed for the shipyard to follow to the letter. The procedure calls for the use of a special apparatus of the type available from Gardner Laboratory\*. It consists essentially of an electric motor mounted on a flat metal plate and a mechanism through which the motor will impart a reciprocating motion to a sponge (held in a metal box) lengthwise across a test panel clamped to the plate. The test panel specified is a glass plate, but steel panels can be used. Prepare the test panel as described in Method 6-1. Place it in the instrument. Soil the panel with the following mixture:

Raw Umber	35 grams
White petrolatum -	6 grams
Mineral spirits -	40 milliliters.

Wet the sponge in distilled water and rub with cake grit soap as directed. Start the machine and after 25 cycles (50 separate strokes), remove the sponge, clean in running water, rub with cake grit soap as before, and run another 10 cycles (20 strokes). Remove the panel, rinse with running water and a clean sponge, allow to dry, and examine for change in color or gloss.

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\* Bethesda, Maryland.

## II-A6-7

### Resistance to Oil and Grease Method 6 - 7

Reference: F.T.M. Std. No. 141a, Method 6081

Obtective: To determine resistance of coating to oils and greases of the type used in engine rooms.

#### Procedure

Prepare test panels as described in Method 6-1. With the panels in a horizontal positions place spots of each oil and grease in at least two or three places over the surface of the paint. Mark the spots in a suitable manner. After a suitable exposure period (at least 24 hours), remove most of the material with a soft cloth, followed by a light wipe with a cloth or tissue wet with a suitable solvents such as mineral spirits. The solvent chosen must be noninjurious to the coating. The panel may then be rinsed under a gentle stream of cool water while using a soft cloth or a tissue. Wipe dry, and inspect for visual defects such as change in color, change in gloss, blistering, etc.,

## II-A6-6

### Coating Stability During Storage Method 6-6

Reference: F.T.M. Std. No. 141a, Method 3022

In examining a new coating for possible use in the yard, it is important to know if it can be stored satisfactorily. This is especially important where the materials may not be used for many months. This test involves a simple procedure of taking a sample from a carefully stirred container of newly received material, storing the sample for several months, and then examining the condition of the sample. Method 2-2 should be followed, as well as the procedures outlined in F.T.M. Std. 144a, Method 3022, in making the inspection.

A convenient method of observing pigment settling of a coating in the laboratory is to fill a 100-ml graduated glass cylinder with the material and set it aside for observation. Periodically, the amount of separation of clear liquid, which becomes visible, can be recorded. At the end of the test, hardness of cake and ease of redispersion can be checked with a probe.

## II-A6-9

### Volume of Nonvolatile Material in Coating Method 6-9

Reference: ASTM D-2697-68

Objective: To determine the volume nonvolatile matter in solvent-type coatings.

#### Procedure

(a) Dry film/wet film thickness ratio. This method maybe used to estimate the expected coverage of a paint, or for routine quality assurance testing. Apply the coating to a flat nonporous substrate using a drawn-down blade. Immediately determine the wet film thickness by one of the methods outlined in Method 3-4(a). Allow the coating to dry according to product specifications. Determine the dry film thickness as described in Method 3-4(b). Divide the dry film thickness by the wet film thickness, multiply by 100, and record the result as apparent volume percent nonvolatile.

(b) Standard ASTM method. This method is based on Archimedes buoyancy effect and is subject to error because void spaces may or may not be wet out by the immersion media. However, when determinations are made by one laboratory, sufficient accuracy should be achieved to permit the accurate calculation and comparison of coverage rates of various competing products.

A stainless steel disk (6.0 cm in diameter and 22-gage thickness) is to be prepared for suspension in liquid by attaching a fine wire through a hole near the circumference of the disk. Dry the disk in an oven at 105 C for 10 minutes, then allow to cool. Using an analytical balance, weigh the disk in air, then in the liquid selected for immersion. During immersion, the liquid should be at least 3/4 inch above the disk and subsequent weighings should be to the same depth. Record the temperature of the liquid; then obtain the specific gravity of the liquid at that temperature.

Calculate the volume of the disk as follows:

$$G = A - B$$

where

G = the disk volume in milliliters,  
A = weight of the disk in air,  
B = weight of the disk in liquid, and  
S = specific gravity of the liquid at test temperature.

Synthetic Seawater, Preparation of  
Method 6-8

Reference: ASTM D-1141-52, Formula A

The dry salt to be used in preparation of synthetic seawater is obtainable from Lake.Products Company\*. The dry salt is to be mixed with deionized water, distilled water, or tap water containing less than 500 parts per million of total dissolved solids. The following ratios are to be used: 41.953 grams salt per liter of water or 5-1/2 ounces per gallon of water.

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\* 1254 Grover Road, St. Louis, Missouri 63125.

Rating of Panels According to Accumulation  
of Marine Fouling Organisms  
Method 6-10

The rating of shipbottom paints according to accumulation of marine fouling organisms requires a trained observer. therefore, commercial, marine exposure stations are generally engaged for exposure of test panels so that fouling observations can be made by skilled technologists. However, even an inexperienced observer can distinguish the difference between a clean and a badly fouled test panel.

It is common practice to give an arbitrary overall rating of fouling based on the observer's experience. The rating may be on a 100 to 0 or a 10 to 0 scale with the high number designating no fouling, and the 0 rating referring to complete fouling. Other ratings are made between these extremes based on the **total** fouling accumulation. In addition, the observer generally gives ratings for the kinds and amounts of marine fouling; both hard (barnacles, mollusks, annelids, bryozoa, hydroids, etc) and soft (algae and scum). Besides the rating of fouling, the observer usually notes coating condition; with a description of any visible film failure (eroding, chalkings checking, cracking, peeling, or blistering) or corrosion of the steel substrate. The examination of panels is usually on a frequent, possibly once-a-month, basis. Photographs are taken to maintain a pictorial record of coating performance.

## II-A6-10

Determine the weight nonvolatile content of the liquid coating material as described in Method 2-110. Calculate the specific gravity (g/ml) of the coating material from the weight per gallon determination as described in Method 2-3. Dip the disk in the liquid coating material such that 1/4 to 1/2 inch of the wire is coated. Allow the coating to drain properly and blot the bottom edges of the disk so that beads do not dry. Dry the coated disk using the same drying schedule as used for the weight nonvolatile determination. Cool the disk. Weigh the coated disk in air, then in the selected liquid medium in the same manner as for the uncoated disk. Record the immersion liquid temperature. Calculate the volume of the coated disk as follows:

$$H = \frac{C-D}{S}$$

where

H = the coated disk volume in milliliters,  
 C = weight of the coated disk in air,  
 D = weight of the coated disk in liquid, and  
 S = specific gravity of the liquid at test temperature-

Calculate the volume of the dried coating, F, in milliliters, as follows:.

$$F = H-G$$

Calculate the volume of the wet coating applied to the disk as follows:

$$V = \frac{C-A}{WXP}$$

where

V = the wet coating volume in milliliters,  
 w = grams of nonvolatile matter in 1 gram of wet coating, and  
 P = specific gravity of the total coating material.

Calculate the percent volume nonvolatile in the liquid coating as follows:

$$\frac{F}{V} \times 100 .$$

Report with the percent volume nonvolatile, the displacement liquid, and the method of drying the film.

Rating of Panels According to Accumulation  
of Marine Fouling Organisms  
Method 6-10

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Leaching of Toxicants from  
Antifouling Paints  
Method 6-11

In cases where the minimum leaching rate of toxicant needed to prevent marine fouling has been established, the shipyard may wish to determine the leaching rate from a new coating as a relatively quick method of estimating its effectiveness. For example, minimum leaching rate of copper has been established as between 7 and 10 micrograms per square centimeter per day. Lower rate is indicative of ineffectiveness and higher rate is wasteful of toxicant.

The method described by Fountain<sup>(1)</sup> is useful for this purpose. In brief, a sandblasted glass panel, 7.5 x 10 x 0.3 cm, is painted on both sides with the antifouling paint. The panel is immersed in 1500 ml of clean seawater, previously well aerated by bubbling, adjusted to a pH of 8.10 + 0.05 and a chlorinity of 17 parts per thousand and maintained at 25 + 1 C (77 + 2 F). The panel is rotated at 100 rpm about its longest axis of symmetry for 1 to 4 hours. The amount of copper in solution is then analyzed by the method described and the rate of leaching calculated therefrom.

It is wise to again test for leaching rate after the panel has been exposed in a large volume of seawater for an extended period of time (1 to 2 months).

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(1) Reference 243, Appendix III-A. Fountain, M. K., Screening Antifouling Paint for Sustained Leaching Rates, Symposium: Natl. Assoc. of Corrosion Engrs., October 5-7, 1966.

PREFAILURE EVALUATION TECHNIQUES  
FOR MARINE COATINGS

PART III - TECHNICAL LITERATURE SURVEY OF  
EVALUATION PROCEDURES

PREFAILURE EVALUATION TECHNIQUES  
FOR MARINE COATINGS

PART 111 - TECHNICAL LITERATURE SURVEY OF  
EVALUATION PROCEDURES

Discussion

Test procedures for the evaluation of organic coatings and coating materials are of considerable number. Many of the established procedures are found in a relatively few reference-type books, which are described below. However, a very large number of additional tests are scattered throughout the technical literature.

The procedures, found in the major reference books are of the well-authenticated, highly dependable nature, that have attained this status by long, involved investigations and widespread use by many different industries.. These reference books are briefly described and discussed as follows.

Federal Test Method  
Standard No. 141

The Federal Test Method Standard 141 is an approved publication by the Commissioner, Federal Supply Service, General Services Administration, for the use of all Federal agencies. It contains approximately 300 test methods acceptable for use in conjunction with Federal purchase specifications. Most of the methods duplicate or refer to ASTM standard methods.

The Standard is available from the Superintendent of Documents, U. S. Government, Washington, D. C. The price is \$3.75 per copy.

ASTM Annual Standards

ASTM Standard Methods are basically established as referee methods to use in case of dispute between buyer and seller. Hence, emphasis is on accuracy, reliability, and reproducibility. Two volumes of the Standards relate to the problem of testing organic coatings. Part 20 concerns paint and paint materials, specifications and tests, including naval stores and aromatic hydrocarbons. Part 21 covers paint tests for formulated products and applied coatings films. Both parts may be purchased separately from American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

### Paint Testing Manual

The Paint Testing Manual by Gardner and Sward, is largely a descriptive of test methods in a general way, in an attempt to aid in the selection of the optimum method compatible with the material being tested, and the intended service application. The descriptions of the test methods are quite general, and are not intended to be cookbook procedures for conducting the tests. The Manual is of great help in deciding what tests should be run, but procedural directions for conducting the test must be obtained elsewhere. It is also available from ASTM, 1916 Race Street, Philadelphia, Pennsylvania 19103.

### Steel Structures Painting Manual

The Steel Structures Painting Manual is published in two volumes. Volume 1 - Good Painting Practice - is especially valuable as a guide to the complex field of the preparation of metal surfaces for receiving paint, and the techniques used for the application of paint to complex structures. Volume 2 - Systems and Specifications - contains valuable data on the selection and application of paint systems for use in a wide range of service conditions. These volumes are available from the Steel Structures Painting Council, 4400 Fifth Avenue, Pittsburgh, Pennsylvania 15213.

### General Comments on the Technical Literature

The literature survey conducted in this present study was drawn mainly from technical publications reported in Chemical Abstracts, Official Digest, The Iron Age, Journal of Paint Technology, Corrosion, and Materials Protection. The papers studied were published in the period from 1960 through 1972.

The technical literature, in general, can be relied on to indicate areas of extreme interest and intensive exploration. However, it must be emphasized that the technical literature is not a satisfactory source of approved or reproducible test procedures. By far, the greatest majority of test methods reported have been developed for special purposes, and frequently suffer in any attempts to expand their use to other applications without involved study.

Major interest appears to be in the area of exterior and accelerated exposures. The consensus of most writers is that accelerated tests can give valuable comparative information, but in most cases cannot be directly correlated with an expected service life. Many people have expressed the desire for an improved method for the early determination of an expected service life. It appears that this is generally a difficult task, since performance varies with penetrant case, its surface preparation, the technique used for coatings application, and the conditions to which the film will be subjected. In short, the design of a "black box" to predict paint durability appears very unlikely in the foreseeable future.

The military provide extensive-specifications for protective coatings according to intended use. Many practical testing procedures can be found by simply examining a specification. For example, MIL-P-23236(374)\* is concerned with qualifying coatings for steel ship tanks for fuel, and saltwater ballast. Methods are given for dry time, gloss, appearance, recoatability, adhesion, flexibility, and immersion resistances to boiling water, aviation fuel, salt water, hot seawater, and hot seawater spray.

Similarly, specific tests developed, evaluated, and standardized by ASTM are a prime source of reliable procedures, and are referenced herein by ASTM Method Number.

### Paint Properties Measured by Special Tests

#### Abrasion Resistance

Abrasion or wear resistance tests are proposed by many workers as a prime part of any paint evaluation program. Included are studies by Cheever, et al<sup>(72)</sup>, Ashton<sup>(15)</sup>, Devoluy, et al<sup>(204)</sup>, Groebler, et al<sup>(247)</sup>, Boller<sup>(336)</sup>, and Orgonas, et al<sup>(307)</sup>.

Averchenko, et al<sup>(66)</sup> claimed that 100 to 200  $\mu$  quartz sand in slurry form gave good indication of erosion resistance of enamel coatings. Fenaroli<sup>(100)</sup> showed that spraying powdered quartz on varnish surfaces caused a loss of gloss which was proportional to the abrasion resistance. Orgonas and Delahunt<sup>(330)</sup> described a method of evaluating hull coatings on spinning disks in seawater-saild slurry.

Apparently, it is accepted that abrasion tests are desirable, but test details are still a major point of discussion.

#### Accelerated Deterioration, Coating Tests

Since time is an extremely valuable commodity, interest has been high in attempting to compress the time factor by studying accelerated tests. An indication of the degree of interest in the subject is the number of literature reviews and "state-of-the-art" studies that have been published. Chronologically, these include publications by Nowacki<sup>(421)</sup>, Richardson<sup>(417)</sup>, Harvey<sup>(382)</sup>, Hearst<sup>(346, 322)</sup>, Talen<sup>(358)</sup>, sakura, et al<sup>(270)</sup>, Preuss<sup>(184)</sup>, Brand, et al<sup>(161)</sup>, Kuenstler, et al<sup>(178)</sup>, Hamner<sup>(132-139)</sup>, Kanevskaya<sup>(49)</sup>, Von Fraunhofer<sup>(27)</sup>, and Gray<sup>(13)</sup>.

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\* References appear in Appendix III-A.

Talen(<sup>332</sup>) has discussed the conditions required to predict paint performance. He concludes that testing programs must take into account

- (1) the intended use
- (2) the conditions imposed
- (3) the nature of the substrate
- (4) the application method
- (5) the curing conditions
- (6) the paint film composition, and
- (7) the type and thickness of the film.

In an earlier paper (395), the same writer pointed out that tensile tests, stress-strain relationships, elongation, and modulus could be used to correlate with expected service life of organic coatings.

Yakubovitch, et al (408) have also pointed out that elasticity is an important factor in the development of cracking in paint films.

(273) have used stress-strain measurements to predict exterior durability of value films.

Campbell(<sup>368</sup>) and Deterding, et al(<sup>292</sup>) have used permeability measurements to predict service life. Campbell's work appears to be related to the Cleveland Condensing Cabinet. Molinski(<sup>258</sup>) has related film porosity to corrosion resistance, and showed that a change in film density occurs just preceding the start of visible surface deterioration. Naumova(261) studied electrical conductivity and vapor permeability as a means of measuring film durability.

Nicoberg (390) used passivation to study protective ability of coating films. Phillips(407) explored the physics of paint films and found a relationship between durability, adhesion, tensile strength, and critical pigment volume concentration. Babel(<sup>33</sup>) used electrical pulses to measure resistance-time curves as an indication of blister resistance. Hearst(90) showed that changes in electrical properties of immersed coatings correlated with durability data. Cesterle et al (104) found that infinitesimal changes in film hardness correlate with durability. Walter(195), Helmen(<sup>171 172</sup>), and Eley, et al(166) have each correlated hardness changes with durability data. Ritter(<sup>83</sup>) found that erosion rate did not correlate with gloss retention or chalking.

Skov, et al (<sup>275</sup>) found both nitric acid resistance and salt fog exposures to be valuable screening tests for corrosion-resistant coatings.

Supel, et al (<sup>150</sup>) accelerated the evaluation of coating films by using very thin coatings. Jedlicka, et al(<sup>137</sup>) studied the acceleration of durability face by using very thin metal substrates which would show early corrosion visible from the back of the steel panel.

Svoboda, et al<sup>(191)</sup> propose alternate humid and dry cycling with xenon lamp radiation as an accelerated procedure. Lion, et al<sup>(211)</sup> propose a wet test chamber as being superior to either humidity or salt fog tests.

Microscopic evaluation for early detection of failure patterns has been proposed by Lindquist, et al<sup>(387)</sup> and Gilch<sup>(401)</sup>.

Many workers in the field of marine paint systems have pointed out, that meaningful test procedures must reflect the peculiar conditions found in service. Field, et al<sup>(242)</sup>, Devoluy, et al<sup>(204 205)</sup>, and Dick, et al<sup>(797)</sup> have proposed that velocity is important, and have used a rotating wheel to simulate ship motion.

Field, et al<sup>(242)</sup> and Brown<sup>(377)</sup> insist that heat and cold, and high and low humidities should be included as test factors.

Alternate exposure to fresh and salt water has been used by Konokotin, et al<sup>(386)</sup>, Smith, et al<sup>(277)</sup>, Neal<sup>(262)</sup>, and Dear<sup>(38)</sup> to demonstrate the "pumping" effect of varying osmotic pressure.

Bacon, et al<sup>(424)</sup> used electrolytic resistance to shorten time-to-failure criteria. Savacchio, et al<sup>(271)</sup> used sonic pulses to accelerate film degradation. McGlothlin, et al<sup>(257)</sup> designed a special environmental room to simulate temperature changes, rain, etc.

Condensation of moisture on paint film surfaces has been used by Higgins<sup>(289)</sup> to design the Cleveland Condensing Cabinet. Jones<sup>(412)</sup> changed the design slightly, and showed it to be equally valuable in metal corrosion studies. Hennige, et al<sup>(300)</sup> added low temperature, ice and frost formation, as critical elements. Putscher<sup>(20)</sup> added UV radiation and oxidizing atmospheres. Koretskaya, et al<sup>(139)</sup> included thermal and optical shock (rapid cycling). Gauguli, et al<sup>(344)</sup> showed that temperatures of 25 C gave faster deterioration than at 40 C, which actually required more time to accomplish, deterioration than did normal outdoor exposures.

Other variations of the accelerated durability evaluation equipment, have included strong ultraviolet exposure, explored by Estrada<sup>(381)</sup>, a tropical cabinet designed by Hendey<sup>(299)</sup>, the EMMA, by Caryl<sup>(33)</sup>, and the EMMAQUA, reported by Caryl, et al<sup>(369)</sup> and PaPillo<sup>(181)</sup>. Elser, et al<sup>(167)</sup> have explored the use of a mercury-doped xenon lamp, and claimed that it increased the rate of film deterioration. The "dew-cycle" Weather-Ometer, as developed by Steig<sup>(278)</sup>, has been studied by Stanton<sup>(22)</sup>, Northwestem Society for Paint Technology ~ (216, 102), and Suzuki<sup>(190)</sup>. This instrument is claimed to be very "valuable" in determining early indications of chalking and loss of gloss, but is less valuable for determining general durability.

The Weather-Ometer and the various modifications thereof have been the subject of many studies to determine the degree of correlation with service life experience. The following tabulation presents a chronological list of several of these studies and the findings.

## TABULATION OF WEATHER-OMETER EVALUATIONS

<u>Worker</u>	<u>Reference</u>	<u>Correlation with Outdoor Exposure</u>	<u>Comments</u>
Rischbieth, et al	392	No	Not good for primers
Cody	378	No	Surface and application import
Nowacki	370,288	No	Varies with coating type
Harris	373	No	Should include condensation
Anon	314	No	Some do, some don't
Schellenberg	310	Yes	Xenon arc preferred
Brown, et al	232	Yes	For alkyd-amino resins
Fullard	244	Yes	Xenon arc preferred
Ali, et al	226	No	Relative failure is misleading
Neal	263	No	Inconclusive
Epple.	241	Uncertain	Correlates with Florida, not with Norway
Papenroth, et al	266	No	Many important factors neglected
Tabata, et al	223	Yes	Correlates with 3 years in J
Mitton, et al	214	Yes	For Fade-chalk only
van Laar	224	No	Does not include corrosive gases
Papenroth, et al	218	No	Too many critical factors
Ashton	115	No	Requires other tests also
Azan	116	Yes	For Structural Steel in Louisiana
Kanevskaya, et al	138	Yes	Has developed conversion factors
Lorenz, et al	141	No	Predictions unreliable
Harrison	134	No	Must be tailored to each use
Papenroth	105	Yes	With certain problems
Fitzgerald, et al	85	Yes	5 days = 6 months
Viktorova, et al	111	Yes	With Magadan exposures
Cervený, et al	40	No	Climatic changes not included
Cosma, et al	41	?	Agrees with country, not urban
Hoffman	47	Yes	Constant reproducibility
Mitten	55	?	Reliability can be improved



<u>Worker</u>	<u>Reference</u>	<u>Correlation with Outdoor Exposure</u>	<u>Comments</u>
Oakley	57	Yes	Correct relative order
Blachowicz, et al	2	Yes	If compared with proper controls
Annovi.	1	Yes	High-pressure xenon lamp better

From the above tabulation, it can be seen that the majority of investigators feel that the results obtained in a Weather-ometer are not reliable. However, many workers feel that the reliability can be improved by attention to certain details. For the most part, however, the instrument appears to be a valuable tool for screening purposes. Final decisions regarding projected service life, however, should await actual end-use service experience.

#### Adhesion

The adhesion of organic coatings to their substrates is probably one of the most critical determinants in the durability of organic coating films and, ironically, one of the most difficult properties to measure. The technical literature contains many review and state-of-the-art papers, such as those published by Ueki<sup>(281)</sup>, Smirnov<sup>(276)</sup>, Hata<sup>(250)</sup>, Mullen<sup>(180)</sup>, Lewis, et al<sup>(140)</sup>, Harris<sup>(133)</sup>, Zorll<sup>(113)</sup>, Oesterle<sup>(59,25)</sup>, Ries<sup>(62)</sup>, and Minami<sup>(23)</sup>.

A large number of investigators have been concerned with a definition of adhesion and its relationships with other paint film properties. For example, Thelen<sup>(419)</sup> has demonstrated that surface contamination, oxide films, passivation surface energies, rheology, surface roughness, trapped air, and chemisorptive forces are all involved in adhesion. The loss of adhesion can be the result of many factors influencing any of the above components. Zubov, et al<sup>(396)</sup> have shown that adhesive bonds are time-dependent and are a function of internal stresses in the resin component.

Johnston<sup>(384)</sup> states that adhesion is primarily a surface matter, depending on the chemical composition of the first few molecular layers of each surface. Bullett, et al<sup>(318)</sup> have confirmed Johnston's (above) findings, and have emphasized the importance of surface cleanliness. Walker<sup>(312)</sup> showed that moisture plays an important part in adhesive bonds. Diffusion of water into the bond weakens it. Drying out the bond area causes a recovery of bond strength. de Vlieger<sup>(240)</sup> and Neumann<sup>(143)</sup> have confirmed Walker's (above) findings and have related blistering to osmotic pressure plus the bond weakening by water,

Irtuganova, et al<sup>(136)</sup> have formulated an equation showing the relationship between paint film durability, time to saturate coating with a corrosive solutions adhesion, inhibition and rate of accumulation of the corrosive medium

Corcoran<sup>(126)</sup> demonstrated that the stresses present in organic films is a major determinant in adhesion, and has suggested methods of calculating these stresses using beam theory.

Heertjes, et al<sup>(91)</sup> described adhesion of paint films in terms of two parameters--the viscous behavior and the strain necessary to break a bond between the film and the substrate. The approach was used to explain the effect of moisture on adhesive bonds. Kuksin, et al<sup>(51)</sup> used quasi-equilibrium energy to characterize intermolecular interactions occurring at a paint film-metal interface with good results.

Asbeck<sup>(32)</sup> has demonstrated that both adhesion and cohesion are involved in the retention of paint films on any surface.

It is apparent from the literature that the process of adhesion is not well understood; consequently, its measurement is proving to be very difficult. This is reflected in the many methods of measurement that are described in the literature.

Watanabe, et al<sup>(29)</sup> have used ultrasonic vibrations to study interface and intercoat bond strengths. Reddy, et al<sup>(26)</sup> Hoffmann<sup>(403)</sup>, Phillips<sup>(407)</sup>, Anon<sup>(334)</sup>, Bullett<sup>(338)</sup>, Zorll<sup>(284)</sup>, and Anon<sup>(230)</sup> have all used "pull-off" tests which utilize objects cemented together with the paint in question, or objects cemented to the surface of the paint film using a high-strength adhesive

Takahashi, et al<sup>(331)</sup> used impact wedge bending tests and cup punching tests (both involve a high degree of deformation) to apply high strains to the paint-metal interface.

Drisko, et al<sup>(295)</sup> used steel panels bonded together by the paint system being studied, and cured. The force necessary to separate the panels was equated to adhesive forces.

Tooke, et al<sup>(280)</sup> claim that actual measurement of adhesion may never be attainable. He suggests a dimensionless "adherence number" obtained by using a simple angular scribe-stripping technique, which correlates well with the qualitative results obtained by the knife test.

Brantley<sup>(398)</sup> has related Adherometer results to work functions, and calculates "work ofhesion" which appears to correlate with practical tests such as the knife test.

Peel tests have been used by Sherlock, et al<sup>(146)</sup> and Kupfova<sup>(95)</sup> with apparently good results.

Aleinikova, et al<sup>(200)</sup> have used a pneumatic adhesiometer for measuring the adhesion of epoxy resin to steel surfaces, with good correlation with other test data.

Hoffmann, et al<sup>(411)</sup> measured the pressure necessary to lift a paint film from its substrate. Anon<sup>(157)</sup> has described a method for measuring adhesion by using impact resistance.

Dunkley, et al<sup>(380)</sup>, Rossini<sup>(268)</sup>, and Newell<sup>(24)</sup> claim that cross-hatch testing gives good results, although Newell<sup>(24)</sup> prefers torque testing of a bolt head immersed in an uncured film and the system allowed to cure.

Kronstein<sup>(253)</sup> has used a combination of sonic vibration and saltwater immersion to evaluate adhesion of marine paints to steel substrates. Myers, et al<sup>(260)</sup> has used a similar technique but employing ultrasonic vibrations.

Kingcome<sup>(348)</sup> and Schmidt<sup>(187)</sup> have both used water jets to test the adhesion of paint films to steel, and the suitability of the coating for naval applications.

In summary, many methods for exploring adhesion have been studied. The results obtained appear to indicate that no really outstanding procedure has yet been devised. This is probably due to the fact that it is extremely difficult to divorce adhesion from cohesion, film integrity, surface conditions, etc, enough to be sure of what is really being measured.

#### Antifouling Tests for Bottom Coating Systems

Antifouling coatings are highly specialized materials and, to determine their effectiveness, require additional testing over and above that employed for other marine coatings. Standard coatings test procedures are used by Devoluy, et al<sup>(204)</sup> Laurie<sup>(325)</sup>, and Partington<sup>(354)</sup> to determine film integrity. Intercoat adhesion of the antifouling topcoat to the anticorrosive midcoat is a large consideration and routine coatings tests are always performed on the entire paint system in addition to each component coating. A new test is synthetic sea water immersion of panels in a hydrodynamic double chambered tank (o). Also, fouling and corrosion bear directly upon each other and studies have been made by Van Londen<sup>(152)</sup> Holman, et al<sup>(347)</sup>, Anon<sup>(365)</sup>, Anon<sup>(425)</sup>, and Munk, et al<sup>(100)</sup> which elucidate this interaction. Because of the heavy reliance of marine engineers upon cathodic protection as a tool to fight corrosion, testing programs for examining bottom paints by Lohr, et al<sup>(20)</sup>, Anderton, et al<sup>(229)</sup>, and Anderton<sup>(313)</sup> have included a study of the compatibility with cathodic protection. The requirements for cathodic protection outlined by the U.S. Navy are covered in Chapter 9190, Preservation of Ships in Service

Once it has been established that an acceptable paint system has been obtained, the effectiveness of the antifouling topcoat becomes of primary concern. Antifouling paints depend upon the timed-release of a water-soluble material which is toxic to fouling organisms. To examine their effectiveness, studies have been suggested which examine each parameter of this mechanism. The Woods Hole treatise<sup>(422)</sup> remains relevant as the most comprehensive reference available in spite of its age. Many current articles by Lohr, et al<sup>(20)</sup>, Dick<sup>(79)</sup>, Dolgopolskaya, et al<sup>(80)</sup>, Van Londen<sup>(109)</sup>, Bult<sup>(122)</sup>, and Anon<sup>(365)</sup> present a brief and general overview noting the state of the art of antifouling evaluation.

The conventional static, raft-type immersion test has long been used as an accepted method for evaluating the performance of antifouling, as noted by the following investigators: Woodford<sup>(30)</sup>, Dick<sup>(79)</sup>, Van Londen<sup>(109,152)</sup>, Guillen, et al<sup>(131)</sup>, Alumbaugh, et al<sup>(201)</sup>, Laurie<sup>(325)</sup>, Van Londen, et al<sup>(333)</sup>, de Wolf, et al<sup>(340)</sup>, Partington<sup>(354)</sup>, Birkenhead, et al<sup>(69)</sup>, and Kingcome<sup>(413)</sup>. Immersion conditions vary as typified by Banks<sup>(68)</sup> report of studies conducted in brackish water, sheltered sea, and in open sea. Dolgopolskaya, et al<sup>(81)</sup> consider that exposures in a tropical environment are sufficiently severe to present an accelerated index of performance. Many accelerated test procedures have been published which range from biological to mechanical. Suggested biological procedures employ such organisms as guppies, Weisfeld<sup>(112)</sup>; snails, Subklew<sup>(279)</sup>; Daphnia, Dolgopolskaya<sup>(82)</sup>; and Antemia salina, Mawatari<sup>(97)</sup>. A study of the effect of copper on diatoms by Kucherova<sup>(177)</sup> indicated that an accelerated index of toxicity was obtained in the laboratory as compared to data from similar studies in actual seawater. Mechanical accelerated devices range from simple rotors, Dick, et al<sup>(79)</sup>, to elaborate devices. This was the subject of an entire NACE conference<sup>(249)</sup> in 1966.

Many simulated service tests are suggested by Dick, et al<sup>(9,79)</sup> and Devoluy, et al<sup>(204,205)</sup>, and the most common are rotor discs and cylinders as suggested by Partington<sup>(354)</sup>, and various rotor apparatuses which spin a series of test panels in actual seawater, as described by Dick, et al<sup>(9,79)</sup>.

A final check of antifouling performance is usually made by patch or quarter tests; that is, by actually applying the experimental coating system to a patch or quarter of a vessel as discussed by Birnbaum, et al<sup>(203)</sup>, Laurie<sup>(325)</sup> and Brown<sup>(410)</sup>.

Laboratory programs are reported by Lohr, et al<sup>(20)</sup>, Driscoll, et al<sup>(8)</sup>, Van Londen<sup>(152)</sup>, Kucherova<sup>(177)</sup>, Gherardi, et al<sup>(296)</sup>, and Partington<sup>(354)</sup> which examine the toxic material (toxicant), and the following investigators examined the leaching rate of the toxicant: Lohr, et al<sup>(20)</sup>, Dick, et al<sup>(79)</sup>, Mawatari<sup>(97)</sup>, Fountain<sup>(243)</sup>, Ghanem, et al<sup>(245)</sup>, Miller<sup>(327)</sup>, Partington<sup>(354)</sup>, and Hanson, et al<sup>(426)</sup>. Several common methods of studying the leaching rate of copper toxicant in the laboratory are described: (1) glycine method by Dolgopolskaya<sup>(82)</sup>, Bish<sup>(119)</sup>, et al<sup>(119)</sup>, Pillai, et al<sup>(182)</sup>, Marson<sup>(213,326)</sup>, and Fountain<sup>(243)</sup>; (2) acid-alkali method by Fountain<sup>(243)</sup>; (3) sodium diethyldithiocarbamate by Ghanem, et al<sup>(245)</sup>; (4) porous plate method by Miller<sup>(389)</sup>; and (5) spinning disc by Van Londen<sup>(361)</sup>.

Fountain<sup>(243)</sup> reports on the comparative effectiveness of the glycine and acid-alkali methods. A study by Brouillette<sup>(4)</sup> of frozen sections of vinyl antifouling paint revealed that compositions with <17, 17-34, and >40 volume percents of  $\text{Cu}_2\text{O}$  toxicant loading showed no, partial, and complete leaching. Van Londen<sup>(361)</sup> reported an improved leaching method, and Hanson, et al<sup>(426)</sup> outlined a procedure applicable for inland stations.

Quality control leaching tests which may be used in production are reported by Marson<sup>(213,326)</sup>. These are based on observing optical density after cycles of sodium glycinate immersion with rotation at 60 rpm. Gorbenko<sup>(87)</sup> reported the observation of colored copper salts on the paint surface and the use of dithizone to identify copper in microbiological specimens on the paint surface to appraise antifouling effectiveness of the paint film.

Beyond studies of leaching rate and its effects, many test procedures are reported which may be characterized as either analytical or biological. Bioassay of fouling communities is a commonly-employed tool and is discussed by Mawatari, et al<sup>(98)</sup>, Dolgopolskaya<sup>(82)</sup>, Mawatari<sup>(97)</sup>, Cologer, et al<sup>(237)</sup>, and Freiburger, et al<sup>(321)</sup>. Bioanalytical approaches are reported by Weisfeld<sup>(112)</sup>, and the rearing of laboratory organisms for lab study of a coating's antifouling potential is mentioned by Kallas, et al<sup>(174)</sup>, Cologer, et al<sup>(237)</sup>, Freiburger, et al<sup>(321)</sup>, and Laurie<sup>(325)</sup>.

Many analytical techniques are suggested in the literature. These include the following: chemical methods by Partington<sup>(354)</sup>; microscopic techniques by De Wolf<sup>(165)</sup>; colorimetry by Chromy, et al<sup>(73)</sup>; observation of film cross sections by Bishop, et al<sup>(36)</sup>; spectrography by Chromy, et al<sup>(73)</sup>; polarography by McCallum<sup>(142)</sup>; X-ray fluorescence by Miniussu, et al<sup>(54)</sup>; X-ray spectroscopy by De Wolf<sup>(165)</sup>; electron microscopy by Lohr, et al<sup>(20)</sup>; scanning electron microscopy by Bishop, et al<sup>(36,119)</sup>; and photometric analyses by Rathack<sup>(309)</sup>.

Comparisons of laboratory versus actual service conditions have been made by Kucherova<sup>(177)</sup> and De Wolf<sup>(293)</sup>. Conger<sup>(125)</sup> has derived mathematical formulas applicable to the performance of antifouling coatings. Still others have devised a special apparatus, such as the Admiralty Water Jet Apparatus by Partington<sup>(354)</sup>, to measure a specific property of a bottom coating system. Because of the recently recognized problem of soft or algae fouling, Hueck, et al<sup>(135)</sup> and Rathack<sup>(309)</sup> have directed their efforts solely to this area.

### Blistering

The relatively important failure mode of blistering has received comparatively little attention. Blistering is, of course, accompanied by loss in bonding to the surface. One literature review prepared by Grubitsch<sup>(207)</sup> includes a discussion of blistering along with several other failure modes. Lowrey, et al<sup>(256)</sup> reviewed the literature of moisture permeability with respect to glass transition temperature of the polymeric content of the film, temperature, pigmentation, and other factors. They concluded that new test procedures were needed, and suggested a series of methods.

DeVries<sup>(8,77)</sup> showed that blistering was caused by a temperature gradient across a paint film, resulting in thermoosmosis, and causing internal pressure buildup.

Babel<sup>(33)</sup> induced blister formation on coated metal panels by applying D.C. electrical pulses, making the panel the anode in a pure, aerated water electrolyte. Resistance-time curves were found useful in predicting the corrosion mechanism and the life of the film.

Boetius<sup>(70)</sup> has demonstrated a relationship between paint film blistering and the presence of water-soluble material in the resin.

Svoboda<sup>(151,191)</sup> as emphasized the role of osmosis in blister formation, and claims accelerated methods fail by not including osmosis in both fresh and saltwater exposures.

Kusano, et al<sup>(254)</sup> show that film thickness is the most important determinant in blister formation, and pretreatments of the metal have little or no effect on blister formation.

de Vlieger<sup>(240)</sup> has shown that thick films blister by the same diffusion process as thin coatings, and states that osmotic pressure is the major influence, being a relationship between ions, metal surfaces, and water.

Harris<sup>(373)</sup> has found that blistering is primarily a function of degree of pigmentation, and stated that blistering is minimal at or near the critical pigment volume concentration. He also claims that water immersion does not correlate with service durability, and recommends cyclical moisture condensation.

Phillips<sup>(391)</sup> has conducted a detailed study of the relationships existing between permeability, pigmentation, blistering, adhesion, etc, and has developed a theory regarding these relationships and molecular forces which he uses to explain paint blistering.

It is not easy to understand why this important area of paint film failure has received such limited attention. Some of the investigations have helped to shed light on the failure process. However, methods of evaluating blistering tendencies have received practically no attention. Water immersion and the Cleveland Condensing Cabinet have been most widely used for metal panels. Other methods such as blister boxes, blister houses, etc, are applicable only for other substrates such as wood, plaster, etc.

#### Capacitance Cell

See "Electrical Tests".

#### Cathodic Protection

See "Electrical Tests".

### Cavitation

It is well known that studies of cavitation damage are going on in various places. However, literature references are quite scarce. At least two symposia are known to have been held on the subject. The National Association of Corrosion Engineers<sup>(239,255)</sup> held one on cavitation corrosion October 5-7, 1966. Several papers of general interest were presented. The American Society of Mechanical Engineers held a similar symposium in 1964. The consensus of test methods discussed at these seminars appeared to be the spinning disc. Many laboratories are known to be using this type of apparatus.

Hobbs<sup>(324)</sup> has used a vibrating apparatus to study cavitation.

Most studies appear to be concerned with cavitation in metals. However, it must be noted that organic coating films are subject to the same type of damage, particularly in areas in contact with moving water at high velocity, such as on a ship's rudder.

### Chemical Resistance

The chemical resistance of organic paint films is an important phase of their performance in service life. With respect to marine coatings, the chemical resistance requirement is as diversified as the potential liquid cargo being shipped.

Chemical resistance tests may be carried out as spot tests or immersion tests, depending on the nature of the chemical.

Yakubovich, et al<sup>(197)</sup> have reviewed methods used in the USSR for coatings evaluations. Seeber<sup>(188)</sup> has devised a cell for determining chemical resistance. Winnicki, et al<sup>(283)</sup> has used labeled atoms to determine rate of penetration of corrosive chemicals. Meuthen<sup>(22)</sup> has reviewed methods used in Germany, and Blomeyer<sup>(3)</sup> has similarly reviewed methods used in Italy. Wildschut<sup>(420)</sup> and Kaatz<sup>(301)</sup> have pointed out the importance of chemical, seawater, and oil resistance for seagoing tankers.

Very little research work was identified as dealing with improved test methods for determining chemical resistance.

### Corrosion

An excellent, concise treatment of marine corrosion has been prepared by Fink and Boyd<sup>(84)</sup> Van Londen<sup>(152)</sup> Hohman, et al<sup>(347)</sup>; and two other investigators, Anon<sup>(365,425)</sup> have observed the interaction between corrosion and fouling. In general, references to corrosion have been directed toward (1) corrosion cell tests, (2) corrosion inspection methods, and (3) comments on filiform corrosion. Each of these is noted as follows.

Corrosion cell tests similar to those used for chemical resistance tests have been used by many workers. By adding accessory equipment for electrical measurements, it is possible to study galvanic effects. The same system has been used in the steel shipping container and the pipeline industry.

By suitable changes in procedure, electrical resistance, porosity, and cathodic protection effects can be evaluated.

Work in this area has been reported by Van Westrenen<sup>(193)</sup>, Van Oeteren<sup>(153)</sup>, and Babel<sup>(33)</sup>.

Corrosion inspection methods are well-referenced and several good sources are available containing recommended methods of inspection for determining the type and extent of corrosion. One of the best is the Marine Painting Manual<sup>(158)</sup>. Good reference material is also available in the Steel Structures Painting Manual and ASTM Standards, both of which were mentioned previously in this review.

Abramchuk<sup>(364)</sup> has published a good review paper describing inspection methods.

Filiform corrosion is a special, thread-like type of growing corrosion that occurs under a paint film. It occurs mostly on steel substrates, although other metals have been known to corrode by this process. Although the subject received considerable attention in the period from 1920 to 1950, very little work has been reported in the period from 1960 to 1972, covered by this survey. Barton<sup>(316)</sup> has shown that filiform corrosion is a function of film permeability. For example, as a coating decreases in permeability by increasing the pigmentations, filiform corrosion tendencies decrease until the critical pigment volume concentration is reached. At this point, the film becomes more porous and general under-film rusting occurs. He also demonstrated that metal pretreatment (phosphatizing, etc) help considerably in preventing filiform corrosion.

The Detroit Society for Paint Technology<sup>(7)</sup> has prepared a series of 10 photographic standards for use in reporting degree of filiform corrosion when using the standard ASTM Method D-2803 for developing filiform corrosion.

### Degree of Cure

It has been accepted practice to check the degree of cure of paint systems by the degree of solvent resistance developed in the film. The solvent used depends on the type of coating being examined.

Wilson<sup>(196)</sup> has studied this procedure and concluded that arbitrary levels of solvent resistance or hardness are not good indications of degree of cure, particularly for epoxy-amine adduct systems. He proposes several other tests be included.



Budrys, et al<sup>(5)</sup> have recommended scuff resistance as a possible index to degree of cure.

Hinden<sup>(323)</sup> has proposed a heated probe to measure indentation under a specified pressure to determine cure. Howard<sup>(93)</sup> has developed an electrical method for measuring rate of cure. However, this requires suspending an electrically conducting material in the paint film being studied. The effect of this suspended material on changing the cure time, as well as the performance of the coating being studied, is subject to question.

### Density

The density of dried paint films has been determined in many ways. Kanevskaya, et al<sup>(209)</sup> have prepared a review of several of these methods, including pycnometer, titration, hydrostatic weighing, direct measurement, and calculation from known component densities.

Khoroshaya, et al<sup>(385)</sup> have developed a titration procedure, involving immersing the sample in KI solution and titrating with ethyl alcohol until the sample sinks to the bottom. The density is calculated from graphs of density of KI solution plus ethanol.

### Drying Rates

Methods of measuring the drying rate of organic coating films have been well worked out for practically all types of coating materials. They are well presented in the ASTM Standards, both Parts 20 and 21, referred to previously in this review.

It is not surprising, therefore, that very few references were found in the recent literature regarding measuring drying rates. Monk<sup>(328)</sup> has designed a new automatic paint drying time recorder, using a needle, sand, and the bandage test simultaneously.

Algeo, et al<sup>(114)</sup> have proposed the need for new methods, including such variables as temperature, humidity, air circulation, film thickness, ultra-violet light, etc. He has modified existing equipment to accomplish the above.

### Durability

Durability is a general term used to designate the useful life of an organic coating, regardless of the type of failure pattern. Evaluation of durability is usually estimated from selected tests or accelerated tests, which are discussed singly elsewhere in this review. However, certain workers have claimed

that some test procedures. give a general indication of durability. Van Londen, et al<sup>(110)</sup> claim that weathering exposure and seawater immersion tests on steel, observing rust formation, correlate well with general durability. Epple<sup>(241)</sup> claims that accelerated tests with low level, interrupted UV exposure correlates well with durability. Ritter<sup>(63)</sup> has measured erosion rate as an indication of film life. Schurr, et al<sup>(273)</sup> show that stress-strain measurements can be used to predict exterior durability. Finally, Katz<sup>(17)</sup> has used Monk microindentation to calculate the elastic factor versus time, which correlates with general durability.

According to Brand<sup>(120)</sup>, durability determinations are far more complicated than is indicated here, and that multiple tests that indicate response to service life factors must be integrated to obtain a final answer.

### Electrical Tests

The use of some form of electrical tests has been a popular study over the years. A literature survey of electrical methods that might be used for following changes occurring in paint films during their life span was prepared by Battelle personnel about 18 years ago. At that time, approximately 450 technical papers dealing with the subject were discovered. Hearst<sup>(297)</sup> has prepared a much more recent survey in 1965, covering the use of electrical methods for predicting paint performance. The same author<sup>(298)</sup> has prepared a general dissertation on electrical properties of coatings as related to their performance. He<sup>(90)</sup> has also published a paper on the changes in electrical properties and the performance of organic coatings.

Electrical tests may be broken down into several groups according to the electrical property being measured. For example, Wormwell, et al<sup>(423)</sup>, Bharucha<sup>(397)</sup>, Koenecke<sup>(405)</sup>, Valentine<sup>(360)</sup>, Rodgers, et al<sup>(267)</sup>, Chromy, et al<sup>(236)</sup>, and Dechaux<sup>(76)</sup> have used the potential developed when coated panels were immersed in an electrolyte such as salt (NaCl) solution to follow film failure and corrosion initiation.

The ohmic resistance imposed by the insulating coating film between a metal panel and an electrolyte bath has been used to follow film deterioration and to determine porosity by Bacon, et al<sup>(424)</sup>, Brown<sup>(410)</sup>, Roller, et al<sup>(393)</sup>, Nitsberg, et al<sup>(390)</sup>, Orzhakhovskii, et al<sup>(353)</sup>, Kutyanin<sup>(349)</sup>, Gherardi, et al<sup>(296)</sup>, Bureau<sup>(162)</sup>, Rothwell<sup>(144)</sup>, and Spellman<sup>(64)</sup>.

De, et al<sup>(379)</sup> have used combined potential, resistance, and capacitance measurements to follow paint film performance in both fresh and salt water.

Pipera et al<sup>(60)</sup> and Obnosov, et al<sup>(58)</sup> have used current intensity measurements to follow coating performance. Obnosov<sup>(58)</sup> relates electrical performance to passivation of the metal surface.

Okamoto, et al<sup>(416)</sup>, Babich, et al<sup>(117)</sup>, Eley, et al<sup>(166)</sup>, Gentles<sup>(345)</sup>, Serebryanikov, et al<sup>(355)</sup>, Rozenfeld, et al<sup>(269)</sup>, Naumova et al<sup>(261)</sup>, Morozumi, et al<sup>(56)</sup>, Baczewski, et al<sup>(34)</sup>, Holtzman<sup>(48)</sup>, Fridman<sup>(42)</sup>, and Mori, et al<sup>(215)</sup> have all studied capacitance and loss factor measurements for following paint film deterioration on immersion in water.

Ward, et al<sup>(28)</sup>, Herman<sup>(46)</sup>, and Kokoska, et al<sup>(176)</sup> have used electrical measurements to determine porosity and locate holidays in paint films. Grey, et al<sup>(129)</sup> have used the zeta meter to examine liquid paint samples, using electrophoretic mobility as an indication of paint quality. Latter<sup>(19)</sup> has developed an eddy current meter for measuring the thickness of paint films on metals.

A completely separate field of investigation has been the impression of a potential on a coated metal panel immersed in an electrolyte such as salt water, to accelerate coating failure. This test procedure appears to be especially valuable in the examination of coatings to be used on cathodically protected surfaces. A good description of the general technique used in this type of study is given in the Paint Testing Manual by Gardner/Sward, referenced earlier in this review. Some of the recent studies in this area have been conducted by Turnbull<sup>(311)</sup>, Aizenfeld, et al<sup>(156)</sup>, Uno, et al<sup>(108)</sup>, Pratt, et al<sup>(61)</sup>, Ghamom et al<sup>(44)</sup>, and Babel (33). This approach is based on the premise that test procedures must indicate performance under service conditions.

### Electron Microscopy

Electron microscopy, particularly the scanning electron microscope. (SEM), has proved to be an extremely valuable tool in the examination of paint film surfaces. The SEM has permitted the examination of the surface geometry of opaque substances, with a high degree of resolution and a depth of field never before possible.

Preuss<sup>(184)</sup> has published a review of paint processes and equipment that describes many uses for the SEM in paint film studies. Other valuable background information of interest to the paint industry is also included.

It is theorized that most paint film failure processes are initiated on the surface of the film. Thus, a study of early changes in the surface topography should develop useful information relative to the mode of failure of that film. Studies along these lines have been conducted by Gilch, et al<sup>(401)</sup>, Lindquist, et al<sup>(387,351)</sup>, Newton, et al<sup>(329)</sup>, Chromy<sup>(163)</sup>, Cheever, et al<sup>(72)</sup>, and Geymayor, et al<sup>(43)</sup>.

Bishop, et al<sup>(119,36)</sup> have demonstrated that the scanning electron microscope can be an especially valuable tool for following the leaching process in antifouling coatings. Both surface and cross-section studies were valuable.

Zorll<sup>(113)</sup> has used the scanning electron microscope to study the morphology of the paint-substrate interface and its relation to adhesion. He also presents a good literature review of this field of study.

### Elongation

Elongation, extensibility, and stress-strain relationships have been studied by many investigators, since it is apparent these properties can influence cracking, flaking, loss of adhesion, etc, during the exposure of a paint film under service life conditions. This is especially true where the coefficient of thermal expansion of a coating differs widely from that of the substrate.

Recent investigators in this field have included Schurr, et al(273), Popryadukhin, et al(183), Boers(160), and Suleimanova, et al(149). The latter have demonstrated that alternate immersion in seawater and drying can place tremendous physical stresses on a paint film.

On the other hand, however, MacDonald(383) has pointed out that certain paint films, such as red lead-vinyl compositions, become stronger on aging, thus preventing the use of stress-strain relationships to predict or follow paint film decomposition.

It should be pointed out that elongation measurements are strictly for laboratory studies, since they require the use of free films, removed from any substrate.

### Erosion

Observing the erosion rate during weathering of a paint film such as an alkyd enamel is reported by Ritter(63) as an index of durability. Abrasive and wear tests such as a 100-200 size quartz sand slurry at rates of 95-280 m/sec are used by Averchenko, et al(66) for determining erosion resistance.

Cavitation-induced erosion has been studied over a wide range of amplitudes and frequencies of the indenter by Grozinskaya, et al(14). Gurevich(88) exposed coatings to a stream of water in a Venturi tube and reported (1) highest cavitation-erosion resistance for epoxy-Thiokol modified vinyls and (2) decrease resistance for systems containing a lacquer over the anticorrosive coating.

Hohman(347) reports test methods employed to study erosion and cavitation which are part of a Bureau of Ships hydrofoil program.

### Evaporation Rate Analysis

Anderson, et al(159) have used the evaporation rate of volatile, radio active tagged solvents from surfaces to study surface geometry, cleanliness, and other surface phenomena of both coating surfaces and substrates before painting that might be involved in determining paint film durability. The technique has also been used to study changes in the surfaces of coatings during exposure. The equipment used for this study is now available commercially under the trade name "Meseran".

### Exterior Exposure

Probably the most widely used and most relied upon test method for evaluating paint film durability is exposure of the films on suitable substrates to the variable conditions of exterior weather. Since this method of evaluation is lengthy (and early results are highly desirable), many people have studied various accelerated methods in the hope that they would correlate with outdoor exposure results. Many of these workers have been mentioned in the "Accelerated Coating Tests" section of this review. They will not be repeated here.

Similarly, evaluation procedures have been standardized to the point where it is only necessary to refer to the proper portion of the ASTM Standards to obtain a well-documented, time-proven procedure for conducting such studies.

On the other hands many workers have contributed additional information as the years have gone by. A large number of technical papers have appeared dealing with the relative merits of various types of organic coatings as evaluated by outdoor exposures. This subject is not considered a part of the present study, and will not be reported here. Similarly, an immense amount of work has been done on exterior durability of paint films on wood. These are also not included in this study, except where specific test procedures are concerned.

Brand, et al<sup>(161)</sup> have surveyed the state of the art of exterior exposure testing, and included a survey of many paint manufacturers and raw materials suppliers regarding special test procedures.

Talen<sup>(332)</sup> has listed the conditions that must be included in a test program to be able to reliably predict service life. Harris<sup>(373)</sup> has delineated the properties of a paint film that contribute to the protection of steel, and has concluded that intermittent moisture condensation must be a part of any test.

Compton<sup>(290)</sup> has extended this study of factors in exposures to the specific field of corrosion prevention in marine atmospheres, and points out the importance of geographic location.

Cook, et al<sup>(399)</sup> have developed a statistical procedure for analyzing outdoor marine exposure results. Byrd<sup>(287)</sup> has shown that results from a series of tests are more reliable than those from any single procedure, and discusses methods of selection of the techniques for specific applications.

copy<sup>(278)</sup> has demonstrated how coating failures can be traced back to basic causes, and how remedies can be designed.

Mackie<sup>(302)</sup> claims that corrosion testing of marine coatings is much more reliable when conducted on shipboard, preferably during a voyage including variable geographic factors. Banks<sup>(68)</sup> has claimed that marine paints should be exposed to fresh and brackish water as well as sheltered and open sea exposures, particularly for buoy protection.

Many studies have, of course, included the use of other techniques to support the data obtained from outdoor exposure, such as the scanning electron microscope. These developments and techniques are discussed under their own section, and will not be discussed further here.

### Film Thickness

The coatings industry uses many magnetic and wet film thickness gages and operator preference usually dictates the use of either Elcometer, Mikrotest Inspector, G.E. Type B Minitector, or Tinsley Gage, etc. Keane and Shoemaker have prepared an excellent report for SSPC on the measurement of paint film thickness on structural steel. This report discusses reference methods and includes an evaluation of field instruments. Daniel<sup>(75)</sup> reports a method for calculating surface volume or an estimation of minimum film thickness on abrasive blasted surfaces.

Both destructive and nondestructive gages are reported. The Tooke Gage<sup>(359)</sup> requires a microscopic V groove through the film. It is unique in that it allows direct observation of a film cross section and is not dependent upon measurement of a secondary property. Unusual nondestructive techniques are reported which are based on (1) electron probe, Anon<sup>(366)</sup>; (2)  $\beta$ -ray scattering, Zaslavskii, et al<sup>(362)</sup>; (3) eddy currents, Latter<sup>(13)</sup>; (4) capacitance measurements, Fridman<sup>(5)</sup>; (5) X-ray fluorescence spectrometry, Driscoll, et al<sup>(83)</sup>; and (6) a meter for measuring nonmagnetic coatings on a magnetic base, Sekowski<sup>(189)</sup>.

Many investigators such as Ghanem<sup>(44)</sup> and Devoluy<sup>(127)</sup> have noted that film thickness is a major consideration in the performance of marine coatings. Banks<sup>(68)</sup> obtained more test situations in a tropical marine exposure program simply by varying film thickness.

Kuksin, et al<sup>(51)</sup> concluded that the energy required to remove a coating was function of film thickness. In a study of film porosity, Herman<sup>(46)</sup> showed that current intensity is indirectly proportional to film thickness. Kusanu<sup>(254)</sup> studied blistering and concluded that film thickness was more important than pretreatment of the substrate. Deterding<sup>(292,339)</sup> noted that the permeability constant increases with film thickness, but thickness was not the most important variable in his study.

Bierner<sup>(409)</sup> recognizes that film thickness is a variable which must be controlled in any evaluation program and further evidence is presented by Levy<sup>(350)</sup> in a study of a rotating filmograph; Algeo<sup>(114)</sup> in a study of dry time records; and Bureau<sup>(162)</sup> in an electrochemical examination of corrosion. the European Coil Coating Association standard tests included measurement method for film thickness and are presented by Meuthen, et al<sup>(22)</sup>.

### Flexibility

The flexibility of paint films is considered to be a major contributing factor in determining the durability of such films. Well-designed and time-tested procedures for evaluating paint film flexibility are available in ASTM Standards.

Meuthen, et al<sup>(22)</sup> have reviewed the methods being used in Europe, and Ashton<sup>(115)</sup> has discussed preferred methods used in Canada.

Serebrennikov, et al<sup>(106)</sup> have devised a test procedure for flexibility involving application of the paint to a strong, transparent film and then passing the coated film back and forth under tension over tile edge of a steel block. The number of passes to give cracking indicates the flexibility of the paint film.

The lack of references on the subject of flexibility is suspected to be due to the already well-established procedures which are available for flexibility evaluation.

### Gloss

Gloss and particularly gloss retention have long been considered as early indications of the durability of paint films. It will be recalled from the discussion on electron microscopy that many workers hold the belief that the paint film surface is the first portion of the film to be affected in the disintegration process. Since gloss is a function of surface smoothness, any changes represent morphological alterations that can often be extrapolated to an expected performance.

Hanserl<sup>(15)</sup> has shown that a relation does exist between surface roughness as determined by profile measurements and gloss. Geymayer, et al<sup>(43)</sup>, has shown the same relationship, using the scanning electron microscope, and related gloss changes to surface degradation on exposure. Changes were detected as early as one month after the start of weathering exposures.

Loss-of-gloss has been used as an early indication of paint film changes by Schellenberg<sup>(310)</sup>, Mitton, et al<sup>(214)</sup>, Mick, et al<sup>(179)</sup>, Elser, et al<sup>(157)</sup>, Kitter<sup>(63)</sup>, Oakley<sup>(57)</sup>, and Blomeyer<sup>(3)</sup>.

Hensel, et al<sup>(208)</sup> have described a new type small-spot gloss meter which can measure the gloss of an area 1/4 inch x 3/16 inch.

Harmmann<sup>(402)</sup> has explored the relationship of illumination to viewing angle and finds both values to be very critical to correlate with visual observations. Braun<sup>(337)</sup> has conducted similar studies and found present gloss meters to be inadequate. He has designed a preferred instrument based on making measurements at the angle of maximum polarization, which varies with the material being examined.

Fenaroli(<sup>400</sup>) has used loss of gloss on abrasion as a measure of abrasion resistance.

### Hardness

The measurement of hardness of paint films is probably the most controversial procedure other than adhesion measurement. Many factors are involved. For example, variations in humidity can cause large fluctuations in hardness, depending on the tendency of the paint film to be plasticized by the presence of moisture. Many other factors such as flexibility, temperature, type of substrate, etc., are major determinants in the measurement.

Ries(<sup>62</sup>) and Meuthen, et al (22) have covered the more popular test methods in reviewing general paint film testing procedures.

Fink-Jensen(~68) has discussed the parameters involved in paint film hardness, the mathematics involved, and several theories of interrelations. A new definition for hardness is given.

Cass(234) has claimed that the Sward Hardness Rocker does not measure hardness, but the modulus of elasticity.

Horkay, et al(<sup>92</sup>), Wilson(<sup>196</sup>), and Van Hoydonck(<sup>192</sup>) have made studies comparing various methods of hardness measurement, and attempted to explain discrepancies.

Helmen(<sup>171</sup>) has investigated the relationship of film history to hardness results, and found a high degree of interdependence.

Zorll(<sup>198,199</sup>) has used pendulum hardness and impact resistance to calculate definite mechanical properties of paint films, which could be correlated quantitatively with known effects of pigmentation.

Katz(17) has used a Monk microindentometer to arrive at an elastic factor from the intercept of mass load and indentation curves. Correlation with aging permitted an evaluation of durability.

Water (195) has separated the factors involved in paint film hardness into two (subsets and relative) classes of properties.

Oesterle, et al(<sup>104</sup>) has developed a procedure for measuring "infinitesimal hardness" changes and has used the procedure to detect early changes in both outdoor and accelerated weathering studies.

Van laar(<sup>375</sup>) has used the Vickers pyramid to determine indentation hardness changes as a paint film weathers. Monk, et al(<sup>304</sup>) have devised a pneumatic microindentation apparatus for measuring paint film hardness. Hinden(<sup>323</sup>) has designed a heated head indentation hardness apparatus. Helmen (171) shows that the Wallace microindentation apparatus gives results of value in interpreting exposure data.



Schellenberg(<sup>310</sup>) has used the pendulum hardness tester to show' that the xenon arc Weather-Ometer corresponded more nearly to outdoor exposure than did the Fade-Ometer.

#### Holiday Detection

The detection of holidays in paint films has received surprisingly little attention in the technical literature. The only major technical paper found is a review by Ward, et al(<sup>28</sup>) which discusses widely accepted industrial practices.

Background information available at Battelle's Columbus Laboratories indicates that many pieces of equipment are available on the commercial market, most of which are specific to some particular phase of coatings applications. For example, the pipeline industry has a preferred method for detecting holidays, that is used only sparingly in other -industries. This is called "jeeping" and is an electrical spark test.

#### Humidity Effects

The effects of humidity on paint films have been discussed in relation to accelerated test methods, durability, flexibility, hardness, and exterior exposure testing. Literature reviews on methods of test, factors involved, and equipment design have been published by Gray(<sup>13</sup>), Newfield, et al(<sup>264</sup>), and Von Fraunhofer(<sup>27</sup>).

Special equipment has been designed by Jones(412) campbell(<sup>3</sup> )  
Cleveland Satiety for Paint Technology(<sup>289</sup>), McGlothlin, et al(<sup>267</sup>), Field,  
et al(<sup>242</sup>), and Lion, et al(<sup>211</sup>).

Many writers agree with Otani, et al(<sup>217</sup>) that a high degree of correlation exists between paint film deterioration and humidity, as well as under-film corrosion and humidity. On the other hand, several writers, as typified by Harrison(<sup>134</sup>) claim that conventional humidity tests are of very doubtful value in predicting service life of organic coatings.

Phillips(<sup>391</sup>) has demonstrated that corrosion protection by an organic coating is best when the water permeability of the film is the lowest. McBane (96) shored that a correlation exists between the coating performance under humid conditions and the diffusion coefficient of the film.

The Joint Corrosion Committee of the FSPI and the SSPC(<sup>74</sup>) has demonstrated that the durability of paint systems varies with the application temperature, and therefore the tendency of moisture to condense on the unpainted surface. Under-film rusting was greatest when substrate temperature was lowest.

Elser, et al<sup>(167)</sup> has obtained evidence that humidity accelerates UV degradation of paint film surfaces.

Guruviah<sup>(89)</sup> found that both oxygen and moisture permeabilities of paint films must be considered in evaluating under-film corrosion. On the other hand, Naumova, et al<sup>(261)</sup> claim that diffusion of moisture through the film is not the decisive phase, but the retardation of the anode process is more important.

Cervený, et al<sup>(40)</sup> have shown that static humidity conditions are not sufficient to simulate service life. Variable cycling of temperature and humidity is necessary to duplicate natural exposures.

It is quite obvious that considerable differences of opinion still exist regarding the best method of humidity testing, as well as the importance of the results. Although not directly referred to in the literature, a vital component of durability testing is considered to be condensation of moisture on the paint film surface. Due to the high osmotic pressures, the driving force causing moisture penetration into the paint film is greatest in pure, freshly-condensed dew.

### Immersion

Two basic types of immersion test procedures are reported. The first type includes fundamental and survey studies which, for example, identify the function of a pigment as described by Valentin<sup>(360)</sup>, or the influence of thick films as described by de Vlieger<sup>(240)</sup>. The second is concerned mainly with performance-oriented test procedures which evaluate film breakdown under an immersion situation. These latter procedures are of practical concern to the evaluation of marine coating systems and consist generally of some modification of (1) simple immersion in a lab tank; (2) lab tank immersion under more rigorous conditions to accelerate breakdown; (3) immersion in the ocean under either normal or accelerated conditions; or (4) a novel procedure or device designed to correlate with a specific parameter or intended use. Simple immersion in a lab tank with visual inspection of coating performance is a common procedure. Some reported solutions included (1) seawater<sup>(377)</sup>, (2) demineralized water<sup>(38,404)</sup>, (3) salt solution<sup>(38,63,355)</sup>, (4) dilute hydrochloric acid<sup>(12,17)</sup>, (5) urea<sup>(355)</sup>, and (7) ammonium sulfate-nitrate combination<sup>(355)</sup>. Seawater immersion conditions vary from (1) small beakers<sup>(377)</sup>; (2) overflow tanks to provide a continuous supply of flowing water<sup>(254,317)</sup>; to (3) aerated seawater<sup>(7)</sup>.

Electrical monitoring of coating performance is commonly described but apparently little used for following breakdown. Gherardi, et al<sup>(296)</sup> mention the monitoring of immersed panels by measuring ohmic resistance. Morozumi, et al<sup>(56)</sup>, Nowak, et al<sup>(306)</sup> and De, et al<sup>(379)</sup> discuss the use of capacitance measurements. Other investigators<sup>(352-423-379)</sup> measured potential, while Sate, et al<sup>(418)</sup> measured A.C. impedance, and Mori, et al<sup>(215)</sup> measured dielectric loss.

Many procedures have been employed to accelerate coating breakdown in immersion tests. These include accelerating one parameter such as temperature (77,277,311,355,418) or cycling test conditions such as (1) fresh water with sea-water from 26 to 100 F<sup>(238)</sup>; (2) brackish water and air with seawater and distilled water<sup>(263)</sup>; (3) dry times with immersion times<sup>(149)</sup>; and (4) tap water with seawater at panel speeds varying from 2 to 30 knots(242).

Natural exposure conditions in the ocean generally are used for static. raft-type immersion studies<sup>(30,97,110,201,301,303)</sup>. Often, several exposure sites are used, such as reported by Cannegieter(7~). Many investigators consider tropical conditions of value because of the severity of the environment(81~376).. Kucherova(177) reported efforts to compare lab and raft exposure data.

Bottom coating systems would normally be subjected to the above type of lab and actual immersion tests. In addition to these, boottops perform in a more aggressive environment and have been examined in tidal (splash zone) immersion by Singleton(107) and Kaatz(301). Hartman, et al<sup>(16)</sup> used aerated seawater, and Suleimanova, et al<sup>(149)</sup> used wet and dry cycles. Tidal Immersion is discussed in greater detail later in this report. Marine coatings for weather decks and exposed equipment have been examined in (1) immersion cycles of brine with. mineral water by Shigorin, et al<sup>(147)</sup>; (2) 10 percent NaCl immersion ranging from -6 to 20 F by Konokotin, et al(386); and (3) under prolonged exposure to steam and hot water by Konokotin, et al(386). Immersion tests for tank coatings generally include resistance to all anticipated cargoes.

Several novel immersion procedures are cited such as (1) use of a radioactive indicator in combination with sweet and seawater cycles by Deterding, et al<sup>(339)</sup>; (2) measuring weight change after specific immersion conditions by Moroznmi, et al<sup>(56)</sup>; and (3) various drums and rotor apparatus(103,99,26,9) as mentioned earlier under Antifouling Testing as well as synthetic sea water immersion or panels in a hydrodynamic double chambered tank (o). A procedure by Svoboda has demonstrated that blistering in paint films can be effected in the laboratory by predipping test panels in NaCl solution before painting and then allowing water to permeate the coating, join with the salt, and produce blistering..

The military specification for tank coatings, MIL-P-2S-S6@4], requires 20 cycles of exposure where each cycle includes (1) 1 week saltwater immersion; (2) 1. week aromatic fuel immersion; (3) 2 hours seawater immersion at 175 F; and (4) 10 seconds exposure to hot seawater spray.

### Infrared Spectrophotometry

Infrared analyses of paints and paint materials have not received the attention in the technical literature that it should, based on the known developments in the field. This method of analysis can be used for a wide range of quality assurance applications, identification of materials, determining adulteration, etc. A literature review and discussion along the above lines has been published by Choate(~).

Studies are reported which employ infrared spectrophotometry for the analysis of binders in marine paints<sup>(206)</sup> and, specifically for vehicles in ship hull paints<sup>(170)</sup>. Another study by Krejcar<sup>(50)</sup> employs the technique to follow aging in paint films. Specific procedures are not mentioned in this report since they vary markedly for the type of study being made.

#### Impact Resistance

Impact resistance, as such, is not usually considered to be a part of durability evaluations, although it is a very important factor in the overall performance of a paint film under service conditions. Several accepted standard procedures are available for evaluating resistance to gravel impact, bullet impact, and bump impact.

Impact resistance is claimed by Hooper, et al<sup>(404)</sup> to be a factor of paint film adhesion. Other investigators, such as Zorll(198,199), claim that hardness, flexibility, and other mechanical properties are involved.

Bender<sup>(35)</sup> has found that the glass transition temperature of the resin component is the controlling factors particularly for primer compositions. Impact resistance is claimed to be the major underlying factor in chip resistance of all paint systems.

#### Ion Exchange Properties

The determination of the ion exchange properties of paint films is a relatively new technique. The procedure involves immersing a clear film of the resin in an electrolyte solution of known pH at controlled temperatures. The liberated or exchanged ions are then titrated with standardized neutralizing solutions.

Khullar, et al<sup>(175)</sup> have shown that the ion exchange capacity has a negative relationship with the corrosion protection efficiency of the binder. That is, the binders with high ion exchange capacities show poor corrosion protection and vice versa.

Ulfvarson, et al<sup>(65)</sup> have found that ion exchange capacity correlates very well with salt spray test results.

This relatively new technique could mean an additional method for evaluation of the corrosion-prevention ability of coating systems.

#### Leaching Rate

See "Antifouling Tests for Bottom Coating Systems".

#### Low Voltage Test

See "Electrical Test".

### Light Microscope

With the introduction of the electron microscope, and the improved scanning electron microscope, the light microscope has been relegated to a position of minor importance by many workers. However, it can still perform many valuable tasks in the examination of paint films. Either transmitted or reflected light can be used. It can thus be used to examine either opaque or transparent materials. Since it is an optical instrument, color of the observed surfaces can be observed.

Tooke<sup>(359)</sup> has recently devised a paint inspection gage which employs a specially designed tool to cut a microscopic V-groove in the painted surface. Examination of the groove can reveal paint film thickness, thicknesses of each coat of a multicoat systems and many other physical features.

### Modulus of Elasticity

There appears to be considerable confusion in the technical literature concerning modulus of elasticity, hardness, flexibility, indentation resistance, etc. Some writers use the above terms almost synonymously. Others call attention to these definition discrepancies. It was noted previously that Cass<sup>(234)</sup> pointed out that the Sward Hardness Rocker actually measures modulus of elasticity. Katz<sup>(17)</sup> uses indentation resistance determinations to arrive at an "elastic factor" for coatings.

zorll<sup>(198)</sup> uses pendulum hardness and impact test results to determine elastic modulus. However, many workers use vibration techniques to arrive at elastic modulus values. Van Hoorn, et al<sup>(415)</sup> calculate elastic modulus from resonant frequencies of a steel strip before and after painting. Babich, et al<sup>(117)</sup> calculate elastic modulus from resonant frequencies of free films. In a later paper<sup>(67)</sup>, they use aluminum foil and apply multiple coats of the paint to obtain resonant- frequency data.

### Peeling

Mekijima, et al<sup>(53)</sup> have studied the causes of paint peeling on structural steel. They discuss the effects of water and water-based contaminants, chalking of primers, and reaction products formed at the interface of the paint layers.

### Penetration

See "Hardness".

### Permeability Measurements

A discussion of the relationship of humidity to permeability of paint film by moisture was presented in the section on humidity. Enlargement on that presentation shows that there are many ways of measuring permeability. Most of these are described in the Paint Testing Manual by Gardner/Sward, referenced earlier in this report, and in the ASTM Standards.

Walker(<sup>312</sup>), Grubitsch(<sup>207</sup>), and Oesterle(<sup>25</sup>) have prepared literature reviews on the factors involved and methods of measuring permeability. Oesterle(59) has prepared a literature review on the relation of paint film structure to osmotic pressure, adhesion, and film permeability.

MacDonald(<sup>388</sup>) presents data indicating permeability of a paint film to water and/or oxygen is not a controlling factor in corrosion prevention. De Vlieger(240), on the other hand, shows a direct relationship between permeability, osmotic pressure, and blistering. Lowrey, et al(<sup>256</sup>) points out a need for improved test methods, and indicates present theories of permeability are outdated. Hay, et al(<sup>45</sup>) show that moisture permeability and retention of both primer and topcoat are related to mold growth and other methods of film deterioration. Studies of sorption/desorption ratios are recommended. Funke(343) shows that water uptake of films constitutes a good measure of film durability.

Guruviah(89) proposed that the ratio of oxygen permeability to water permeability is the major factor controlling corrosion prevention ability of paint films. McBane(<sup>96</sup>) claims that the relationship of humidity resistance to permeability is anomalous. The valid relationship of performance under humid conditions to the diffusion coefficient is the important one.

Phillips(391) claims that corrosion protection is not a function of resin permeability, but for a given resin it is best at lowest permeability. Harris(373) has similarly shown that no simple relationship exists between permeability and deterioration of panels during water immersion. Cycling factors are much more important.

Yaseen, et al(<sup>362</sup>) have studied the relationships existing between permeability, time, temperature, film thickness, etc, and have found an Arrhenius-type equation to be valid.

Nitsberg, et al(<sup>265</sup>) have explored several of the possible ways of measuring permeability of paint films, and find them, for the most parts in good agreement.

Holtzman(48) has applied Bottcher's relationship and Fick's second law to the development of an electrical capacitance method for measuring water vapor transport in organic coatings applied to an impervious substrate. This method also permits the calculation of swelling from small volume changes.

Campbell<sup>(368)</sup> has developed an "accelerated" procedure using a cabinet similar to the Cleveland Condensing Cabinet. Schneider(272) has developed a test procedure for measuring permeabilities of bulk materials such as liquid paints, putties, caulking compounds, etc.

Deterding, et al(<sup>339</sup>Y<sup>292</sup>) have used radioactive trace: techniques to measure water permeability of paint films. In a later paper<sup>(164)</sup>, they point out possible sources for errors in the technique.

Murdock(<sup>259</sup>) has also used tracer techniques to measure permeation penetration depth, total sorptions and other parameters. Glass, et al<sup>(246,86)</sup> have explained the technique to study ion diffusion (such as sodium and chlorine) into paint films.

### Ferosity

Testing paint films for porosity is almost synonymous with holiday detection discussed earlier. The outstanding difference is in the size of the fault to be detected, Porosity detection methods should, therefore, be more sensitive and have better resolution.

Van Oeteren(153) has reviewed the origin of pores and their classification and has discussed several pore-locatting techniques particularly using electrical methods. Grubitsch<sup>(207)</sup> has reviewed general and electrochemical methods for porosity detection as well as other related methods.

Molinski, et al<sup>(258)</sup>, Wkoska, et al<sup>(176)</sup>, and Herman<sup>(46)</sup> have all developed test procedures for detecting porosity. The first two are electronic instruments while the latter is a variation of the electroprint technique.

### Potentiometric Tests

See "Electrical Tests",

### Rait Tests

See "Antifouling Tests for Bottom Coating Systems".

### Rust Evaluation

See "Corrosion".

### Sagging

One literature reference to the study of paint sagging was encountered Makishima. et al<sup>(212)</sup> report a new method where experimental data correlate well with calculated values. The method is suited to the formulator in the laboratory but not to the worker in the field. However, Federal Test Method 141-4493 and -4494 describe methods for rating the sagging of paint films.

### Salt Spray

Because of the highly corrosive nature of salt sprays many variations of chloride-containing water sprays are reported for examining the corrosion resistance of materials. Material performance in salt spray atmospheres is reported to be a useful tool in general screening studies for coatings(65,275,404) for screening pigments in a given resin system(10,134); and for studying specific types of coatings such as steel primers(315,392,13), zinc rich coatings(342), zinc dust primers<sup>(329)</sup>, paints on zinc coated surfaces<sup>(173305)</sup>, weldthrough primers(263), zinc-rich topside coatings(262), marine steel primers<sup>(394)</sup>, and ship topside paints(264). Salt spray procedures are included in test programs examining the adhesion of polymers to metal(419) and of the water and oxygen permeability of a paint film(89). References compare salt spray exposure data with atmospheric data<sup>(223,308)</sup> and with data obtained from exposure in other environmental test cabinets<sup>(27)</sup>.

Some investigators feel that salt spray is the best method for rapid corrosion testing(115,252,277) and that it offers the most consistently correct service prediction over various humidity and accelerated weathering tests. Other investigators cite methods which are quicker such as (1) a new wet chamber, Lion et al<sup>(211)</sup>; (2) a potentiostatic method which is more informative, Clay<sup>(124)</sup>; and (3) a method where 1 minute of exposure equals 2 weeks in a cabinet, Cheever. Still other investigators report negative findings with salt spray test methods such as the inability to draw valid performance prediction, Van Laar<sup>(224)</sup>, and the poor repeatability of these data, Store<sup>(148)</sup>.

### Seawater Immersion

See "Immersion" and "Antifouling Tests for Bottom Coating Systems".

### Service Life Prediction

See "Accelerated Deterioration Coating Tests".



### Settling

Methods for observing the settling of the pigment component of paints in the container have been used for many years. The procedures are usually subjective, since it is generally necessary only to know whether or not the pigment has settled and, if so, if it can be reincorporated with a minimum effort. It is therefore not surprising that very little work is reported in the recent literature.

Papenroth, et al<sup>(219)</sup> have devised a new technique involving pressure increase in a bubble tube when it hits a settled layer, and Veiel, et al<sup>(194)</sup> have used the apparatus to study various paint systems.

### Ship Trials

Widely-differing views are expressed as to the value of ship trials in predicting the service life of marine coating systems. Mackie<sup>(302)</sup> found that the sea environment was unexpectedly more severe than that of a lab situation. Birnbaum, et al<sup>(203)</sup> successfully conducted service tests on 57 ship hulls. Others report service tests in conjunction with raft and lab evaluations, Van Londen<sup>(109)</sup>; and with lab and cathodic protection studies, Anderton, et al<sup>(285)</sup>. However, some investigators including Devoluy, et al<sup>(205)</sup> and Van Londen, et al<sup>(333)</sup>, report that service tests are too slow. These studies use service tests only as a reference point for accelerated or improved laboratory tests.

### Solids Content

The determination of solids content of liquid paint systems is complicated by the fact that many special methods have been developed for specific materials. An examination of the technical literature has revealed that no technical papers were published on the subject during the period covered by this study.

Several facts should be pointed out regarding the determination of paint solids. An examination of the different procedures available as standard methods and as included in other standard methods and specifications of ASTM made about 5 years ago show that about 75 different procedures have been made available for use. Most methods report the results in weight percentage.

Since considerable confusion existed in the past relative to the selection of the proper method for determining solid content of paints, ASTM has developed Recommended Practice D2832-69, Determining Nonvolatile Content of Paint and Paint Materials. This procedure is a guide to the selection of the proper method for making the determination, based on the type of paint or paint material being examined.

If volume nonvolatile matter is required, ASTM Method D2697-68, Volume Nonvolatile Matter in Clear or Pigmented Coatings, is the preferred procedure. This method uses the Archimedes buoyancy effect to determine the film specific gravity in a nonsolvent liquid.

### Surface Preparation

Many people feel that the success or failure of a paint system applied to metal substrates depends largely on the way the surface has been treated to receive the paint. This preponderance of feeling is reflected in the fact that probably the greatest number of references represent the greatest divergence of opinions, procedures, and techniques discovered during this survey.

Literature reviews and general discussions of tests, techniques, materials and effects have been published by Ries<sup>(62)</sup>, Bullett<sup>(39)</sup>, Long<sup>(21)</sup>, Ellinger<sup>(11)</sup>, Gruninger<sup>(130)</sup>, Sagaidak<sup>(145,186)</sup>, Preuss<sup>(184)</sup>, Banfield<sup>(286)</sup>, and Corre<sup>(319)</sup>. Gay<sup>(169)</sup> and Barrillon<sup>(118)</sup> have prepared reviews particularly concerned with shipyards and shipbuilding practices. The U.S. Navy outlines their requirements in Chapter 9190, Presentation of Ships in Service (Paints and Cathodic Protection)<sup>(101)</sup>. The Marine Painting Manual<sup>(158)</sup> has a good section covering surface preparation methods, including an inspection and rating section. Similarly, the Steel Structures Painting Manual, referenced previously, has an excellent section on metal preparation techniques.

Helms<sup>(383)</sup> has authored a NACE report of Committee T-6D giving a specification format for surface preparation for industrial painting.

Devoluy, et al<sup>(127)</sup> has authored Technical and Research Bulletin No. 4-9 of the Society of Naval Architects and Marine Engineers on an "Abrasive Blasting Guide for Aged or Coated Steel Structures".

Rommelts<sup>(221)</sup> has prepared a report (94C) to the Netherlands Ship Research Center on optimum conditions for blast cleaning of steel plate.

Becker<sup>(202)</sup> has published a guide for the flame cleaning of iron and steel before painting. Downing<sup>(294)</sup> has prepared a guide for maintenance painting for steel highway structures that contains a good section on metal preparation.

Fox<sup>(371)</sup> has discussed the Swedish pictorial standards for sandblasting, which have been accepted by ASTM, NACE, and SSPC. Reference to these standards is also found in several ANSI procedures.

An anonymous writer<sup>(367)</sup> has discussed procedures for surface preparation by water-blasting. Shores<sup>(274)</sup> has discussed acid pickling and phosphate pretreatments. An anonymous author<sup>(231)</sup> has discussed methods and problems involved in chemical cleaning as a pretreatment procedure.

Keane<sup>(210)</sup> has described research programs conducted by SSPC on steel surface preparation for painting.

Mayne<sup>(414)</sup> has related rusting of steel to the presence of  $\text{FeSO}_4$  on the surface, which is formed by the catalytic oxidation of  $\text{SO}_2$  to  $\text{SO}_3$  in the presence of rust. Removal of sulfate can materially improve paint film durability.

Andersson, et al<sup>(228)</sup> have explored the effects of various types of iron oxides on steel surfaces on the durability of paint films applied over them. The presence of zinc chromate in the primer was shown to be a very effective method of improving paint film durability.

Chandler, et al<sup>(235)</sup> claim that the presence of mill scale and rust due to weathering accelerate paint film failure. The process is not reduced by rust-inhibitive primers.

Blachowicz, et al<sup>(38)</sup> have found that the so-called chelating primers are excellent on clean steel, but are relatively ineffective in preventing further corrosion on rusty steel surfaces.

Bullett, et al<sup>(018)</sup> have demonstrated that paint durability on steel is a direct function of the surface cleanliness, since contaminants act to injure adhesion.

Mil<sup>(303)</sup> has found that wash primers are extremely helpful in marine coating systems, but they must be matched to the surface pretreatment for best results. In some cases, wash primers were found to accelerate corrosion.

Herpel, et al<sup>(251)</sup> have emphasized that surface preparation of steel should not result in an excessive roughness, as this can be a detriment to coating durability.

Daniel<sup>(75)</sup> has worked out a system for correlating substrate roughness with paint film thickness for optimum performance. Bullett, et al<sup>(121)</sup> have worked out a similar system and have developed an instrument for measuring surface roughness using the rate of air escape under a gasket applied to the surface. A cleanliness meter was also developed. The SSPC<sup>(31)</sup> has described a surface profile comparator for judging the degree of sandblasting of steel.

Cody<sup>(378)</sup> has shown that paint films on structural steel perform according to the type and degree of surface preparation.

Wildschut<sup>(420)</sup> has shown that surface preparation is a prime determinant in the durability of amine-cured epoxy paints used in shipbuilding.

Blachowicz, et al<sup>(37)</sup> found that sanding of steel surfaces gave better performance than wire brushing. Still better results were obtained from phosphoric acid treatment followed by "burning" or heat treatment.

Frank, et al<sup>(128)</sup> developed a paste phosphate treatment that improved paint film durability on steel.

Reeves, et al<sup>(185)</sup> developed a fluoridated chromate treatment which works well for aluminum surfaces and might be expected to work on other metals.

Ichiooka, et al<sup>(173)</sup> have found chromate treatments to work well on zinc and galvanized surfaces before coating.

Kronstein<sup>(253)</sup> has emphasized that interaction between coats should be avoided. He recommends a complex system including surface preparation, removal of entrapped air, application of primers and topcoats using certain precautions, and crosslinking the complete system.

Barton<sup>(316)</sup> has shown that metal pretreatments are effective in reducing filiform corrosion, while etch primers (containing  $H_3PO_4$ ) are not.

Cupr., et al<sup>(320)</sup> have reviewed the literature on phosphate, chromate and alkaline pretreatments.

Negreev, et al<sup>(352)</sup> have shown phosphoric acid to be equally effective as sandblasting for marine finishes.

Culshaw<sup>(291)</sup> showed that freshly pickled steel gave inferior performance to as-rolled plates. Grit-blasted plates gave the best paint film durability.

Vazirani<sup>(154)</sup> has described a new process for surface treatment of steel that gives superior salt spray and humidity resistance.

Subbotina<sup>(357)</sup> has developed a single apparatus for simultaneous degreasing, painting; and curing in a continuous atmosphere of trichloroethylene vapor.

Krutikov. et al<sup>(34)</sup> have described an apparatus for decreasing, etching, and phosphating of metal parts. The new method is claimed to be superior to sandblasting.

### Sunshine Weathering

CarYl<sup>(233)</sup> and Caryl, et al<sup>(369)</sup> have described a device for weathering paint films which uses mirrors to focus the sunlight of the Arizona desert to about 150,000 langleys per month compared to about 16,000 in normal exposure at 45 degrees facing south. The equipment is called EMMA (Equatorial Mount with Mirrors for Acceleration) and EMMAQUA (EMMA + water spray, 10 minutes, 7 times per day). Good correlation with normal outdoor exposure results are claimed.

Von Fraunhofer(<sup>27</sup>) has used a similar setup in England with good results.

Annovi(<sup>1</sup>) has developed a xenon lamp claimed to give equivalent results to EMMA.

### Swelling

Although it has received relatively little attention in the technical literature, the swelling of paint films is considered to be a very important factor in the deterioration of paint films.

Grubitsch(<sup>207</sup>) has included swelling in his review of testing methods for paint films.

Oesterle, et al(104) have measured film-swelling by following infinitesimal hardness changes. Wahlin, et al(282) have used an immersion method to follow volume changes. Electrical resistance and pH changes can be followed simultaneously.

### Tensile Measurements

Many investigators recognize the direct relationship between a coating's adhesion and its performance. Thus, adhesion is often measured by tensile shear as reported by Gusman(372) and Thelen(<sup>419</sup>). Changes in adhesion as a function of time can be followed with tensile measurements on the Instron Tester as reported by Phillips(391). Marine paint performance has been evaluated in this manner by MacDonald(388).

Schurr, et al(<sup>273</sup>) reported tensile-strength versus exposure time to be a measure of a coating's durability. The method has been used generally to follow the rate of deterioration by Gutfreund(<sup>248</sup>), and to study the effects on a coating of radiation, humidity, and atmospheric conditions by Talen(395). One study by Filson, et al(<sup>341</sup>) reports that tensile measurements show that UV radiation is more severe than temperature changes or rain in contributing to deterioration.

Filson, et al(<sup>341</sup>) have studied coating application methods and have shown by tensile strength changes in a coating that stresses during drying affect later breakdown. The Hounsfield ensometer has been used by Phillips(407) to study the physics of paint films and thereby provide insight for studying fundamental properties of films.

### Tidal Immersion

Tidal immersion studies are conducted by mounting coated panels in the tide zone so that they receive alternate periods of wet, splash, and, possibly, dry times. This set of extremely aggressive breakdown conditions is similar to those encountered by boottop coatings on a vessel and splash zone coatings on pillings.

Typical programs using tidal immersion studies have been designed to (1) compare the performance of various paint vehicles, Kaatz<sup>(301)</sup>; (2) define the effect of PVC resin system, and effect of number of coats on coating performance, Yingst<sup>(225)</sup>; and (3) aid in the selection of surface treatment, prime and anticorrosive barrier coating needed for a specific application such as buoys Banks<sup>(68)</sup>; steel piling, Alumbaugh, et al<sup>(227)</sup>; and coastal hydrotechnical installation, Negreev<sup>(352)</sup>.

Programs generally study tidal immersion along with other immersion procedures, such as total or semistatic immersion, Singleton<sup>(107)</sup>.

### Ultrasonic Testing

The use of sonic and ultrasonic vibrations to study modulus of elasticity was discussed earlier in this survey. Ultrasonics have been used by Watanabe, et al<sup>(29)</sup> to study intercoat adhesion failure. Myers, et al<sup>(260)</sup> have used ultrasonics to monitor changes in the mechanical properties of paint films as they age, and find some correlation with adhesion failure.

Vibration of an indenter has been used by Grozinskaya, et al<sup>(14)</sup> to evaluate wear resistance of coating films.

### Ultraviolet Lamps

The subject of ultraviolet exposure was covered in earlier discussion, particularly on accelerated test methods. By and large, UV exposure alone is much less harmful than UV plus moisture. The choice of UV lamps has tended to be in the direction of simulation of the noonday sun spectrum, since this condition has been found to be most injurious.

### Water Vapor Testing

The interrelation of water vapor, permeability, constant condensation and paint film durability was discussed earlier under several subjects. Exposure to water vapor in the form of humid atmospheres is a critical part of any paint film durability evaluation procedure.

Test methods are well recorded in the Paint Testing Manual by Gardner, Sward and ASTM Standards books, both referenced earlier in this review.

Grubitsch(<sup>207</sup>) has prepared a review of test methods that includes water vapor tests.

Kronstein, et al(<sup>406</sup>), Nitsberg, et al(<sup>265</sup>), and Yaseen, et al(<sup>362</sup>) have developed special procedures for moisture vapor testing.

#### Wear Resistance Tests

Practically all the work on wear resistance tests has been discussed earlier under Abrasion Resistance. Evaluation methods are quite similar, indicating the two properties are either synonymous or very closely related.

Van Laar(<sup>375</sup>) has used falling nuts to evaluate wear resistance. A stream of quartz sand has been used by Averchenko, et al(<sup>66</sup>). Zubov, et al(<sup>155</sup>) and Grozinskaya, et al(<sup>14</sup>) have used vibrating tools, varying frequency, and amplitude of the tool as the variable component.

Berger, et al(<sup>317</sup>) have reviewed a series of wear test procedures.

#### Weather-Ometer Evaluation

See "Accelerated Deterioration, Coating Tests".

#### X-Ray Fluorescence

X-ray fluorescence (XRF) spectrometry is reported as- an effective tool for determining the level of heavy metal inorganic or organometallic toxicants in antifouling coatings by Driscoll, et al(<sup>83</sup>). Miniussu, et al(<sup>54</sup>) report that the presence of copper causes higher readings of mercury. In addition to short-range prediction of antifouling performance, XRF is suggested as a tool for competitive monitoring, quality control, and determination of film thickness by. Driscoll, et al(<sup>83</sup>).

APPENDIX III-A

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## APPENDIX III-A

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PREFAILURE EVALUATION TECHNIQUES  
FOR MARINE COATINGS

PART IV - LABORATORY EXAMINATION OF  
SELECTED NEW TEST METHODS

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SELECTED NEW TEST METHODS

In making the on-site visits to shipyards, coating manufacturers, etc, and while examining the published literature, special attention was given to any new and unproven test methods for speeding up the qualification of new ship coating systems. A major requirement is that the test procedure give indication of performance potential in a relatively short time. This means that either the test condition be increased in severity to accelerate failure, or some technique be used to give indication of beginning failure before it is evident in visual inspection of the coating system.

Coating Thickness Versus Time of Failure-

One new technique selected for study is based on the knowledge that thin coatings fail more rapidly in seawater immersion than thicker ones. The refore, it was postulated that it might be possible to expose a marine paint system at various thicknesses observe failure time at each thickness, plot failure time versus coating thickness and then project this plot to find the service life for a recommended thickness of the paint system. The log plot of failure time versus thickness of a coating would be roughly similar to an Arrhenius relationship which has been used to project failure of coatings in some other uses.

Two paint systems were selected for laboratory study of this method:

- (1) Alkyl Zinc Silicate Primer-Chlorinated Rubber, Underwater Coating
- (2) An Epoxy-Polyamide Underwater System Conforming to Specification MIL-P-24441 (Ships).

Steel test panels 6 x 12 x 1/8 inch with rounded edges were sand-blasted to obtain a low profile measurement of about 1.0 roil. A low profile was desired because of the thinness of some coatings to be tested. The zinc-rich primer was applied 1.2 roils thick because this was about the minimum amount that could be properly applied by spraying. The chlorinated rubber tie coat was applied 1.5 roils thick because thinner coats could not be applied over the zinc silicate primer without "cratering" or "eyeholing". This meant that only the topcoat could be varied in thickness. Originally, the plans were to vary the zinc silicate primer in thickness from 0.5-to 1.5 mils, vary the tie coat from 0.5 to 2.0 roils, then vary the topcoat from 0.5 to 4 or 5 roils.

The panels prepared for testing had the following coating thicknesses (each coating measured on a smooth steel surface sprayed alongside the blasted panel):

IV-2

<u>Zinc Silicate Primer</u>	<u>Recommended Tie Coat (Approx)</u>	<u>Chlorinated Rubber Topcoat (Approx)</u>	<u>Total Thickness</u>
1.2	1.5	1.0	3.7
"	"	2.0	4.7
"	"	3.0	5.7
"	"	4.0	6.7
"	"	5.0	7.7

A second set of panels was prepared as described earlier and coated with various thicknesses of Specification MIL-P-24441 Epoxy-Polyamide. This system was applied to the following dry-film thicknesses:

<u>Primer (Approx)</u>	<u>Topcoat (Approx)</u>	<u>Total Thickness</u>
0.5	0.5	1.4
1.0	1.0	2.3
1.0	2.0	3.5
2.0	2.0	4.1
2.0	3.0	5.2
2.0	4.0	6.1
2.0	5.0	7.0
2.0	6.0	8.0

The coated panels described above were subjected to the following tests (all at ambient-room temperature):

- (1) Synthetic seawater immersion\*
- (2) Deionized water immersion
- (3) Alternate seawater wet and dry

The panels in group (1) were also set up for monitoring by electrical measurements as described in another section of this document, "Resistance Measurements to Give Early Indication of Coating Failure".

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\* The synthetic seawater was prepared according to ASTM D-1141-52. (See Method 6-8 in Part II of this document.)

### Synthetic Seawater Immersion

For synthetic seawater immersion, the laboratory tanks comprised two, 20-gallon glass containers (elongated 20-gallon aquariums). They measured 30 x 12 x 12 inches.

The 6 x 12-inch, coated panels were suspended in the synthetic seawater to a depth of 8 inches by hanging them from support racks using an insulated wire. This system electrically insulated the panels from each other and from ground (measured as better than  $10^{12}$  ohms). Spacing between the panels was about 2 inches (center to center). Clear, acrylic strips were placed across the top of the tank and between the panels to maintain a 2-inch center to center spacing; water evaporation was also effectively reduced.

Glass aquarium heaters of 100-watt capacity were used to maintain temperature of the water at  $77 \pm 1$  F. An air-driven aquarium filter was used to filter the water and to maintain a common circulation between tanks. A loop of plastic tubing filled with the synthetic seawater was used to accomplish return circulation between tanks to maintain an equal level in both tanks. Filtered air was bubbled through the water between each pair of panels. The air was supplied through small holes in plastic tubing placed at the bottom, and extending from end-to-end through the center of each tank. The holes were so spaced that air could bubble between each suspended panel. Air flow between each panel was maintained at approximately 1 liter per minute.

Figure 9 shows the two tanks in place on a laboratory work bench. Figure 4 in Part II of this document shows a closer view of one of the tanks, with air bubbling between the panels.

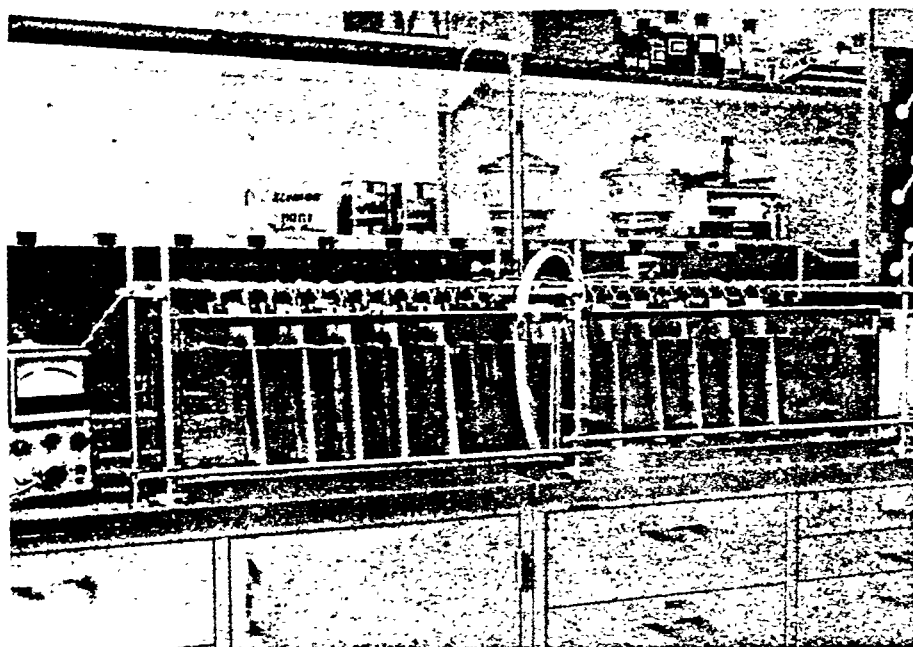


FIGURE 9. TEST PANELS IMMERSED  
IN SYNTHETIC SEAWATER

Duplicate coated panels were exposed, but not side-by-side. The panels were examined weekly for rust, blisters, and other visible signs of failure. Electrical measurements were also made weekly and are discussed in a following section.

Results of the visual examinations (partial data) are shown in Tables 1 and 2. The results obtained are not sufficiently precise to plot and then extrapolate to a failure time for the full coating thickness. However, these data do show a trend toward earlier failure of the thinner panels in each set.

Very few failures occurred in the epoxy-polyamide system after 10 weeks immersion. This was the system *where* coating thickness could be controlled over a wider range than had been possible with the chlorinated rubber system.

In view of the difficulty involved, and the great deal of effort necessary to prepare the large number of panels needed for a test of this type, it is concluded that this procedure should not be used by shipyards as an attempt to obtain early prediction of performance of shipbottom coating systems.

TABLE 1. PANELS IMMERSSED IN SYNTHETIC SEAWATER--CHLORINATED RUBBER SYSTEM

Panel No.	Total Coating Thickness, mil	Blistering and Rusting After Exposure (a)				
		2 weeks	4 weeks	6 weeks	8 weeks	10 weeks
51	3.7	OK	7 small rust spots	>10 small rust spots; few #6 blisters	>10 rust spots; 6 in. <sup>2</sup> MD #8 blisters	Scattered rust--ASTM #7; 6 in. <sup>2</sup> MD #8 blisters
52	3.7	OK	OK	4 in. <sup>2</sup> area of MD #8 blisters	6 in. <sup>2</sup> dense #8 blisters	Few rust spots--ASTM #8; 6 in. <sup>2</sup> dense #6 blisters
61	4.7	OK	OK	>10 small rust spots; 2 in. <sup>2</sup> area of MD #6 blisters	>10 rust spots; 2 in. <sup>2</sup> MD #4 blisters	Few rust spots--ASTM #8; 2 in. <sup>2</sup> dense #2 blisters
62	4.7	OK	1 small rust spot	1 small rust spot	1 small rust spot; 1/2 in. <sup>2</sup> MD #6 blisters	Few rust spots; ASTM #9; 1 in. <sup>2</sup> MD #6 blisters
71	5.7	OK	1 small rust spot	1 small rust spot	1 small rust spot	1 large rust spot; few rust spots--ASTM #9
72	5.7	OK	OK	OK	OK	Few rust spots--ASTM #8
21	6.7	OK	OK	OK	OK	Few rust spots--ASTM #9
22	6.7	OK	OK	OK	OK	OK
41	7.7	OK	OK	OK	OK	3 small rust spots
42	7.7	OK	OK	OK	OK	Few rust spots--ASTM #9

(a) OK - No failure.

ASTM designations for blistering and rusting used when amount became sufficient to rate.

Blistering: MD = Medium Dense.

TABLE 2. EPOXY-POLYAMIDE COATED PANELS  
IMMERSED IN SYNTHETIC SEAWATER

Panel No.	Total Coating Thickness, mil	Visible Condition After Immersion		
		1 week	4 weeks	10 weeks
101	1.4	OK	OK	1 small rust spot
102	1.4	"	"	2 small rust spots
111	2.3	"	"	Few small rust spots
112	2.3	"	"	1 small rust spot
121	3.5	"	"	OK
122	3.5	"	"	"
131	4.1	"	"	"
132	4.1	"	"	1 small rust spot
141	5.2	"	"	OK
142	5.2	"	"	"
151	6.1	"	"	"
152	6.1	"	"	"
161	7.0	"	"	"
162	7.0	"	"	"
171	8.0	"	"	"
172	8.0	"	"	"

Deionized Water Immersion

It is not uncommon to find that a coating will blister more rapidly in deionized, or distilled water, than in salt water. Therefore, the two series of panels prepared as described previously were also immersed in deionized water.

One of the 20-gallon glass tanks (described previously) was used for these tests. Air was supplied to each bottom corner of the tank and allowed to bubble very slowly through the water. This created gentle currents which helped to maintain thermal equilibrium throughout the tank. However, air was not bubbled between each panel as had been done in the synthetic seawater.

The panels were suspended from an aluminum frame built around the tank. They were immersed in the deionized water so that the lower 9 inches of the panel was exposed. Nylon cord was used to attach the panel to the support.

Clear, acrylic strips were placed on top of the tank, and between panels to maintain a 1-1/2-inch center-to-center spacing. A glass aquarium heater was used to maintain temperature at  $77 \pm 1$  F.

Duplicate coated panels were exposed but not side-by-side. They were visually examined periodically for rust and/or blisters. The results of this test are shown in Table 3.

The coatings showed very little failure after 10 weeks immersion. Perhaps the failures were less than in the saltwater immersion because air had not been bubbled between the panels as had been done in the seawater immersion tanks.

Blistering was just beginning to show on some of the thinner coatings after 10 weeks. Thus, there is some evidence that a plot of degree of failure versus coating thickness might be prepared after some longer exposure time, and then used to project the performance of the thicker coatings. However, the duration of this research program was too short to complete this study.



TABLE 3. DEIONIZED WATER IMMERSION OF COATED TEST PANELS

Panel No.	Coating Type	Total Coating Thickness, mil	Visible Condition <sup>(a)</sup> After Immersion			
			1 week	3 weeks	8 weeks	10 weeks
53	Chlorinated- Rubber	3.7	OK	OK	OK	Few #8 blisters
54	Ditto	3.7	"	"	Few #8 blisters	Few #8 blisters
63	"	4.7	"	"	Few #6 blisters	Few #6 blisters
64	"	4.7	"	"	OK	OK
73	"	5.7	"	"	"	"
74	"	5.7	"	"	"	"
23	"	6.7	"	"	"	"
24	"	6.7	"	"	"	"
43	"	7.7	"	"	"	"
44	"	7.7	"	"	"	"
103	Epoxy- Polyamide	1.4	"	"	"	"
104	Ditto	1.4	"	"	"	"
113	"	2.3	"	"	"	"
114	"	2.3	"	"	"	"
123	"	3.5	"	"	"	"
124	"	3.5	"	"	"	"
133	"	4.1	"	"	"	"
134	"	4.1	"	"	"	"
143	"	5.2	"	"	"	"
144	"	5.2	"	"	"	"
153	"	6.1	"	"	"	"
154	"	6.1	"	"	"	"
163	"	7.0	"	"	"	"
164	"	7.0	"	"	"	"
173	"	8.0	"	"	"	"
174	"	8.0	"	"	"	"

(a) OK means no visible failure.

ASTM Designation: D-714, for blister size ratings;

#1 is very small, and #2 is very large.

Alternate Seawater Wet and Dry

Alternate immersion in seawater and drying is used as a test in some laboratories. Expansion and contraction has been reported to cause early failures in coatings. Thus, this test was examined as part of this program.

Two, 5-gallon glass aquarium tanks measuring 16 x 10 x 8 inches were used for the immersion tests. The panels rested on the floor of the tank while leaning against glass rods placed at the top of the tank. The glass rods prevented panel-to-panel contact and maintained panel spacing at 1 inch from center to center.

Duplicate coated panels (as described previously) were placed in the tanks and synthetic seawater was added to immerse the panels to a depth of 9 inches. The panels remained immersed for 11 days; then the seawater was siphoned out of the tanks. The panels were allowed to remain dry for 3 days, then they were inspected for rust and/or blisters. This cycle was repeated five times.

Results of the examinations are shown in Table 4. The data in Table 4 are inconclusive because the 10 weeks exposure time available in this program was not sufficient to carry the panels to ultimate failure. However, it is evident that the method has limited potential as an accelerated test. Again, because of the effort involved in preparing the large number of test panels, and the lack of positive results, this test method is not recommended for shipyard use.

TABLE 4. ALTERNATE SEAWATER IMMERSION AND DRYING OF COATED PANELS  
(2 WEEKS EACH CYCLE)

Panel No.	Coating Type	Total Coating Thickness, mil	Visible Condition After Immersion and Drying Cycles			
			2 weeks	4 weeks	8 weeks	10 weeks
55	Chlorinated-Rubber	3.7	OK <sup>(a)</sup>	OK	1/2 in. <sup>2</sup> MD #6 blisters	No change
56	Ditto	3.7	"	"	Few rust spots--ASTM #9	No change
65	"	4.7	"	"	OK	1 small rust spot
66	"	4.7	"	1 small rust spot	1/2 in. <sup>2</sup> MD #6 blisters	No change
75	"	5.7	"	OK	OK	2 small rust spots
76	"	5.7	"	"	"	OK
25	"	6.7	"	"	"	"
26	"	6.7	"	"	1 small rust spot	3 small rust spots
45	"	7.7	"	"	OK	Few scattered rust spots--ASTM #10
46	"	7.7	"	"	Few rust spots--ASTM #9	Few scattered rust spots--ASTM #9
105	Epoxy-Polyamide	1.4	"	"	1 small rust spot	1 small rust spot
106	Ditto	1.4	"	"	OK	OK
115	"	2.3	"	"	"	"
116	"	2.3	"	"	"	"
125	"	3.5	"	"	"	"
126	"	3.5	"	"	"	"
135	"	4.1	"	"	"	"
136	"	4.1	"	"	"	"
145	"	5.2	"	"	"	"
146	"	5.2	"	"	"	"
155	"	6.1	"	"	"	"
156	"	6.1	"	"	"	"
165	"	7.0	"	"	"	"
166	"	7.0	"	"	"	"
175	"	8.0	"	"	"	"
176	"	8.0	"	"	"	"

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(a) OK means no visible failure.

ASTM designations for blistering and rusting used when amount became sufficient to rate.

Resistance Measurements to Give Early  
Indication of Coating Failure

A number of investigators\* have described various electrical measurements, such as resistance and capacitance, to give early indication of coatings failure. It was felt that one such method should be examined further to determine its value to shipyards in obtaining early indication of performance potential of marine coatings for use under water.

Both the chlorinated rubber and the epoxy-polyamide systems. (prepared as described previously for exposure in synthetic seawater) were subjected to the electrical test. The same apparatus and panels used for the "Synthetic Seawater Immersion" were used in this investigation with the addition of the following modifications and equipment:

Electrical contact was made to each panel through a copper wire soldered to the top edge of the panel. The soldered area was then painted with the same material used to coat the panel. Only the tip end of the wire was exposed for connection to the measuring circuit.

The equipment for monitoring the changes in electrical resistances of the coating consisted of the following: (1) a Keithley Model 610C solid state electrometer, (2) a shunt box, (3) a switch box, and (4) a platinum electrode. The electrometer was used to measure the potential difference between the test panel and the platinum electrode, and the IR drop across the shunt resistor. The shunt box permitted the insertion of a shunt resistance across the test panel and platinum electrode. The switch box was used to open or close the circuit to the test panel. A platinum electrode was chosen as the reference electrode because of its inert qualities. Coaxial cable (RG 58 A/U) was used to make connections between the various circuit components. A schematic of the equipment and circuit is shown in Figure 10 on the following page.

Voltage measurements were made for each panel and the coating resistance calculated at the start of the test, and once each week thereafter. The following formula was used to calculate resistance:

$$R = R_s \left( \frac{E_o}{E_s} - 1 \right)$$

where

$R$  = the coating resistance in ohms,

$R_s$  = the shunt resistance of  $1.021 \times 10^4$  ohms,

$E_o$  = the open circuit potential between the test panel and the platinum electrode (with essentially no current flowing), and

$E_s$  = the potential difference across the shunt resistor (or the potential between the test panel and the platinum electrode with a significant current flowing).

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\* See Part III, section titled "Electrical Tests".

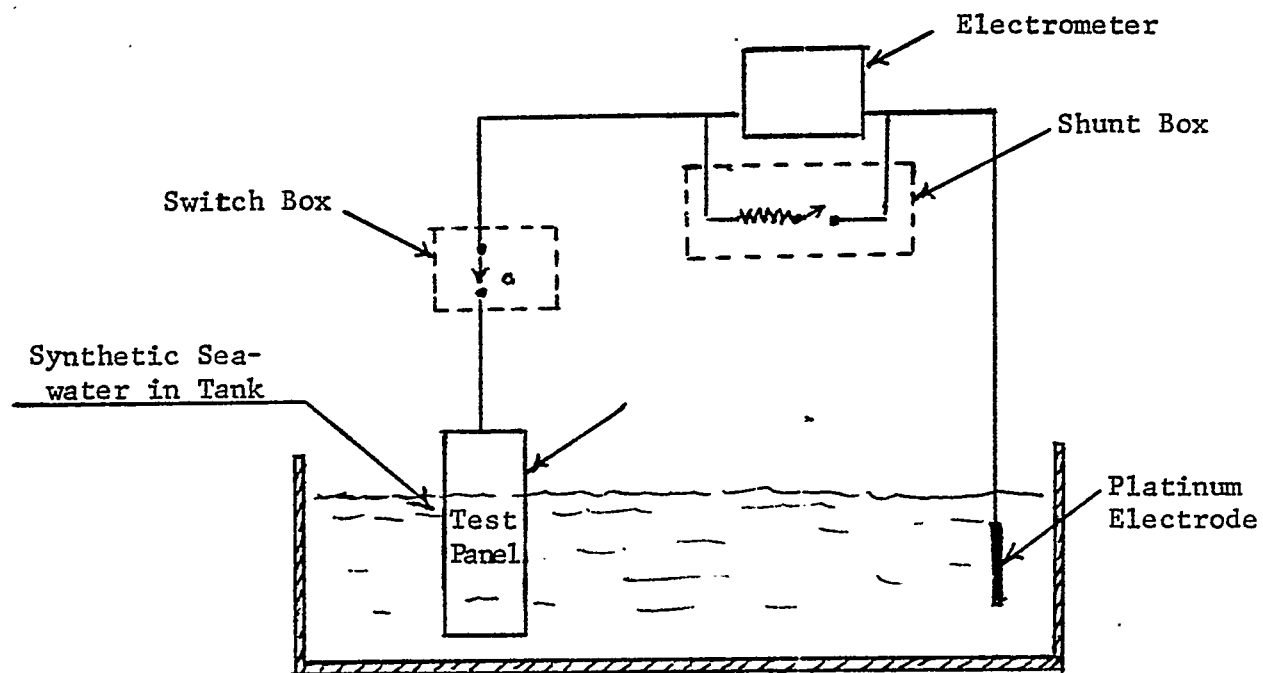


FIGURE 10. SCHEMATIC OF CIRCUITRY USED TO MONITOR ELECTRICAL RESISTANCE OF COATINGS IMMERSED IN SYNTHETIC SEAWATER

The resistance measurements on the coated panels are shown in Tables 5 and 6.

TABLE 5. ELECTRICAL MONITORING OF PANELS IMMERSED IN SYNTHETIC SEAWATER--  
CHLORINATED RUBBER COATINGS

Panel No.	Total Coating Thickness, mil	Electrical Resistance Measurements After Various Immersion Times						
		Initial	2 Days	9 Days	16 Days	23 Days	37 Days	58 Days
51	3.7	35.0 K	100 K	137 K	64.0 K	20.4 K	13.7 K	11.4 K
52	3.7	21.4 K	20.1 K	19.2 K	14.3 K	10.5 K	13.8 K	10.4 K
61	4.7	55.7 K	28.9 K	31.9 K	41.6 K	39.2 K	22.6 K	15.7 K
62	4.7	107 K	92.9 K	116 K	43.9 K	35.3 K	28.7 K	20.9 K
71	5.7	18.3 K	43.2 K	48.2 K	25.1 K	37.5 K	55.0 K	38.3 K
72	5.7	35.9 K	56.1 K	51.8 K	54.1 K	52.1 K	83.5 K	40.8 K
21	6.7	46.2 K	62.8 K	64.9 K	139 K	150 K	109 K	88.6 K
22	6.7	8.7 Meg	1.68 Meg	10.5 Meg	21.1 Meg	11.4 Meg	16.3 Meg	8.55 Meg
41	7.7	24.0 K	25.5 K	30.6 K	26.2 K	29.8 K	31.3 K	30.6 K
42	7.7	90.9 K	292 K	197 K	398 K	302 K	253 K	471 K

Note: K =  $10^3$  ohms; Meg =  $10^6$  ohms.

TABLE 6. ELECTRICAL MONITORING OF PANELS IMMERSSED IN SYNTHETIC SEAWATER--  
EPOXY-POLYAMIDE COATINGS

Panel No.	Total Coating Thickness, mil	Electrical Resistance Measurements After Various Immersion Times						
		Initial	2 Days	9 Days	16 Days	23 Days	37 Days	58 Days
101	1.4	68.9 K	57.7 K	48.0 K	34.5 K	32.1 K	24.3 K	17.1 K
102	1.4	46.5 K	74.0 K	63.8 K	46.0 K	39.8 K	38.3 K	23.0 K
111	2.3	64.5 K	94 K	44.2 K	47.4 K	45.5 K	35.3 K	29.3 K
112	2.3	65.1 K	102 K	101 K	83.8 K	85.2 K	57.9 K	42.5 K
121	3.5	83.4 K	245 K	405 K	527 K	392 K	391 K	368 K
122	3.5	67.0 K	143 K	386 K	212 K	152 K	132 K	141 K
131	4.1	302 K	1.96 Meg	762 K	408 K	3.7 Meg	2.89 Meg	528 K
132	4.1	15.7 K	13.1 K	13.0 K	12.7 K	12.8 K	13.7 K	12.4 K
141	5.2	30.6 K	32.7 K	66.7 K	64.6 K	85.2 K	40.1 K	49.2 K
142	5.2	32.7 K	31.2 K	61.3 K	71.5 K	86.7 K	97.0 K	99.1 K
151	6.1	42.5 K	55.1 K	113 K	161 K	282 K	144 K	221 K
152	6.1	67.4 Meg	≥42.8 Meg	16.0 Meg	20.4 Meg	18.4 Meg	19.4 Meg	23.5 Meg
161	7.0	565 K	159 K	283 K	546 K	1.14 Meg	3.18 Meg	577 K
162	7.0	53.0 K	43.1 K	98.1 K	112 K	123 K	161 K	177 K
171	8.0	43.6 K	40.8 K	66.7 K	68.4 K	49.0 K	69.5 K	28.4 K
172	8.0	>>10.2 Meg	>38.8 Meg	19.6 Meg	22.4 Meg	≈26.8 Meg	29.5 Meg	23.5 Meg

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Notes: K =  $10^3$  ohms; Meg =  $10^6$  ohms.

Because of the numerous references to electrical methods for giving early indication of coating failures it *had* been postulated that this series of tests would produce results of great importance to the shipyards. It was believed that the measurement of resistance versus exposure time would be particularly valuable when used with the two series of coated test panels having controlled variations in coating thicknesses. However, results were disappointing. Positive trends were not evident from these data even when resistance values were plotted versus exposure time. It is obvious that even a tiny flaw in a panel can cause a great decrease in the measured resistance of the coating on a test panel. Moreover, resistance values can increase during exposure, apparently because of healing of pores or flaws, or possibly from an increase in resistance as the corrosion product builds up in pores or voids.

If resistance measurements are to be used to monitor coated panels, it appears desirable to use a test cell to expose only a limited area of the panel surface, and none of the panel edge. Even with the great care used in laboratory preparation of the-coated panels, it is obvious that they were not perfect enough for this work. Therefore, the shipyard will probably find that the use of resistance measurements to monitor coatings performance would be very difficult. Moreover, enough replicate samples will probably be needed to obtain statistically meaningful results.

The few trends that were noted showed generally higher resistance values for the thicker coatings, as expected. Moreover, higher resistance values were generally noted for the epoxy system than for the chlorinated rubber system.



Evaluation of Possible New Technique for  
Measuring Adhesion of Marine Coatings

Methods for measuring adhesion of marine coatings are woefully inadequate, especially when the coating is on a rough, blasted surface. Much has been published in this area (as noted in other sections of this report). Many investigators are still searching for better ways to measure adhesion of coatings (note discussion of literature review in Part III of this document). The literature search did not bring forth any new method for examination in this program. However, a brief exploratory investigation was made of a new idea put forth by the authors. The idea was to use a sudden pressure release to disrupt the bond between the coating and its substrate.

Test panels were prepared and coated as described previously, but in smaller size (4 x 4 inches). The full (recommended) thickness of each of the coating systems (chlorinated rubber and epoxy) was used for the tests.

A one-gallon autoclave was prepared for the trials by removing the stirring shaft and cooling coil. The test panels were placed in the chamber with wooden blocks between them to act as spacers. One set was tested while immersed in distilled water by bringing pressure up to 5,000 psi. The panels were held at this pressure for one hour. The pressure was then released and dropped to 2,000 psi in 5 seconds, and atmospheric pressure within 1 minute.

The second set of panels was subjected to a nitrogen atmosphere. The pressure was raised to 1,500 psi and held for 3 hours. Again, the pressure was released and the drop to atmospheric pressure occurred in 2 minutes.

In both tests, the chlorinated rubber coating system blistered and was easily removed from the test panel by scratching with a knife. The epoxy system, on the other hand, did not blister and retained its excellent adhesion.

Thus, it was found that a pressure release test could be used to show differences in adhesion between these two coating systems. However, additional research beyond the scope of this program would be needed to refine the test procedure and develop it into a quantitative test for all kinds of coatings.

Feasibility of Using Ultrasonics to Indicate  
Degree of Surface Preparation

The following coating systems were prepared to study the possibility of using special ultrasonic techniques to show degree of surface preparation:

- (1) The chlorinated rubber system described previously  
(7.7 roils total thickness)
- (2) The epoxy-polyamide system described previously  
(8.0 mils total thickness).

Each of these coating systems were applied over the following surfaces: rusty steel, hot-rolled steel with scale, and blasted hot-rolled steel.

A nondestructive testing technique is needed to determine the adhesion of coatings to various substrates, and differentiate between various conditions of the substrate. Conventional ultrasonic techniques are not capable of evaluating the coating to steel adhesion (or substrate differences) due to the resolution limitations and sensitiveness to such factors as beam inhomogeneity, part geometry, and surface characteristics of the material. Considerable advances have been made by the subcontractor in the field of ultrasonics, and it appears that high-resolution ultrasonic instrumentation might be used to determine the adhesion of coatings to steel parts, and differentiate between different steel substrate conditions. Six panels 6 inches by 9.25 inches as described below were evaluated using high-resolution ultrasonic techniques.

<u>Panel No.</u>	<u>Coating System</u>	<u>Total Panel Thickness, inch</u>	<u>Surface Condition of Steel Prior to Coating</u>
211	Chlorinated rubber	0.133	Rust
231	Chlorinated rubber	0.128	Ideal
222	Chlorinated rubber	0.275	Mill scale
281	Epoxy polyamide	0.135	Ideal
251	Epoxy polyamide	0.131	Rust
262	Epoxy polyamide	0.273	Mill scale

### Ultrasonic Technique

The technique for the evaluation employed standard ultrasonic pulse-echo principles in conjunction with specially developed high-resolution instrumentation, as shown in Figure 11. Longitudinal mode sound wave pulses were propagated directly into the coated panels via a portable water bubbler gravity fed system with a special lead metaniobate ultrasonic transducer. These pulses are reflected from the top surface and bottom surface of the coated panel. The reflections received are converted into electronic radio-frequency signals. The ultrasonic transducer is specially designed and heavily damped to operate at a very high frequency to provide excellent time resolution.

A special broad-banded pulser-receiver unit is used for pulse generation and radio-frequency signal processing. The band width of the receiver is 35MHz to 40 MHz. The ultrasonic transducer and cable assembly are carefully impedance matched to the pulser-receiver so as to have a response of approximately 0.5 MHz to 25 MHz. The central frequency of the specially manufactured 1/4-inch-diameter transducer used is 9 MHz. The amplified RF signal of the receiver is displayed on a Tektronix Model 453A oscilloscope. As with the standard thickness-measuring technique, the horizontal sweep of the oscilloscope can be calibrated so that one full-scale sweep represents both the material thicknesses and displays both the top surface and bottom surface of the coated panel. The horizontal sweep may also be compressed to view the signal wave train and observe the decay or attenuation pattern for each coated panel.

### Coated Panel Examination

The ultrasonic instrumentation and technique earlier described were utilized to evaluate the six coated steel panels. Four areas along the longitudinal axis and equidistant apart were observed from one side only for each panel, using the technique.

Prior to evaluating the panels, the oscilloscope was calibrated for thickness along the horizontal sweep. For this calibration, three cold-rolled steel standards were used. Their dimensions were 5/8 x 2 x 2 inches, 1/4 x 2 x 2 inches, and 1/8 x 2 x 2 inches. The oscilloscope traces for each of these thickness calibration standards are shown in Figures 12, 13, and 14. All parameters were maintained constant for evaluation of the coated steel panels. The ultrasonic settings were

- (1) pulse amplitude = 3.0 (dial setting)
- (2) gain control = 1.5 (dial setting).

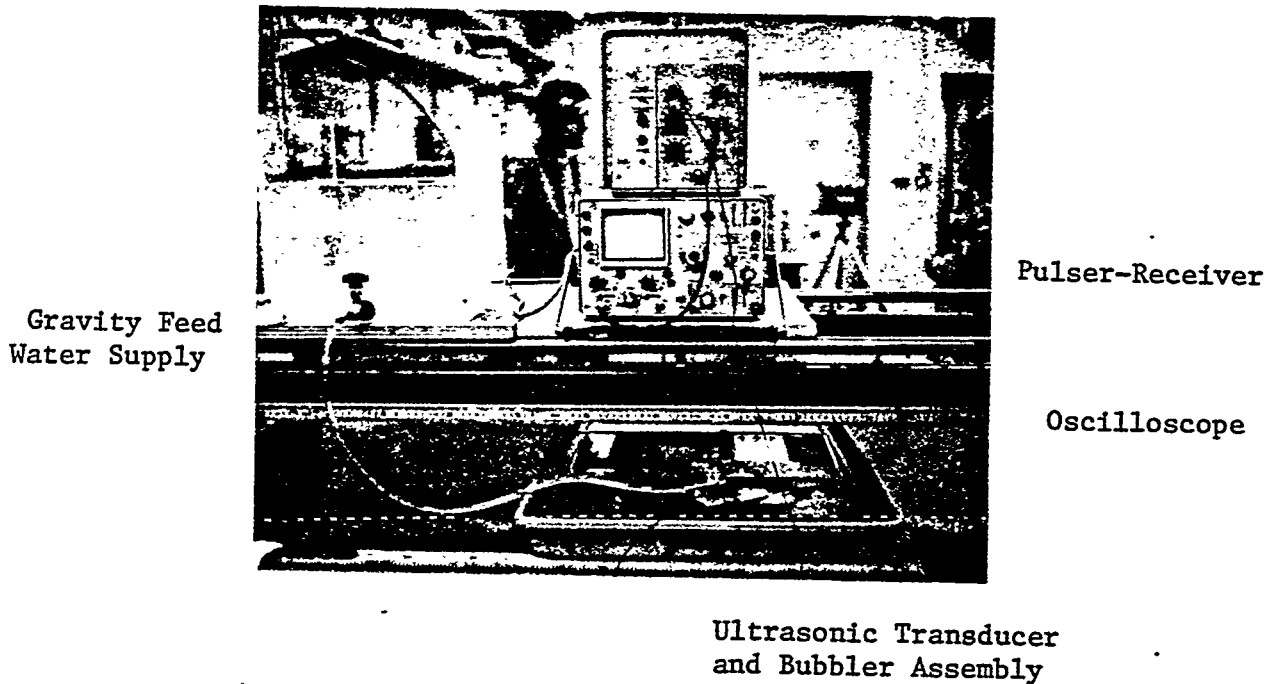


FIGURE 11. HIGH-RESOLUTION ULTRASONIC SYSTEM UTILIZED  
FOR EVALUATION OF THE COATED PANELS

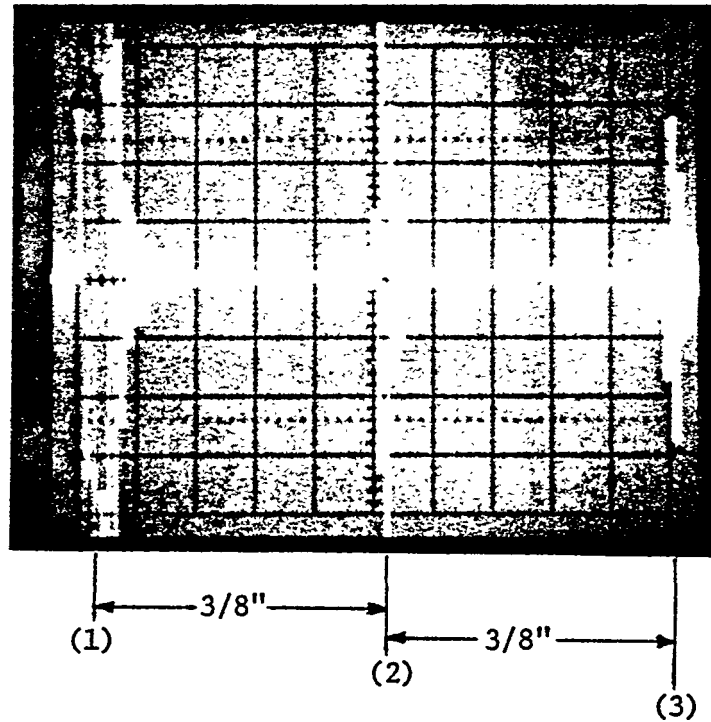


FIGURE 12. OSCILLOSCOPE DISPLAY OF 3/8 INCH THICK COLD-ROLLED STEEL CALIBRATION STANDARD

- (1) Signal received from top surface of steel calibration standard.
- (2) First signal received from back surface of steel calibration standard.
- (3) Second signal received from back surface of steel calibration standard. This is a multiple repeat of the first back surface signal received.

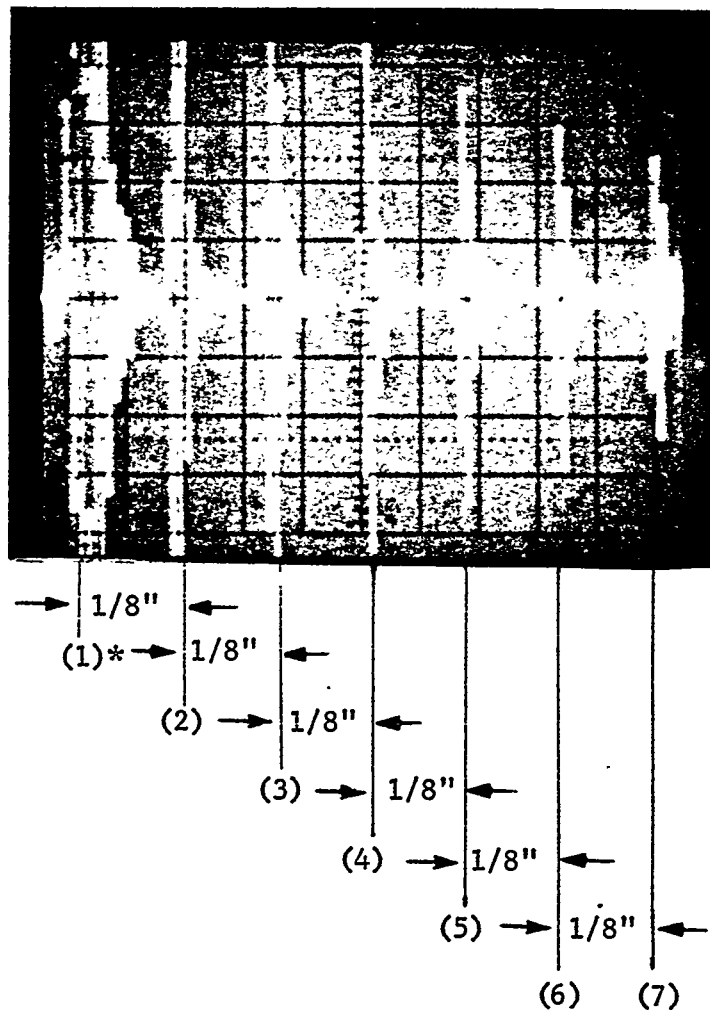


FIGURE 13. OSCILLOSCOPE DISPLAY OF 1/8-INCH THICK  
COLD-ROLLED STEEL CALIBRATION STANDARD

- \* (1) Signal received from top surface of steel calibration standard.
- (2) First signal received from back surface of steel calibration standard.
- (3) to (7) Multiple repeats of steel material thickness.

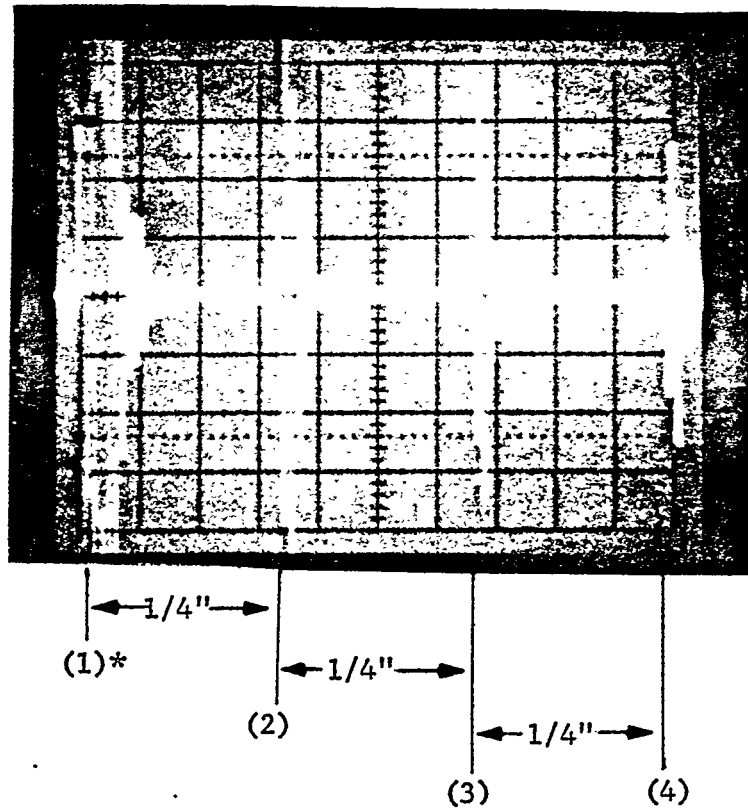


FIGURE 14. OSCILLOSCOPE DISPLAY OF 1/4-INCH THICK COLD-ROLLED STEEL CALIBRATION STANDARD

- \* (1) Signal received from top surface of steel calibration standard.
- (2) First signal received from back surface of steel calibration standard.
- (3) Second signal received from back surface of steel calibration standard.
- (4) Third signal received from back surface of steel calibration standard.

The oscilloscope traces for each of the four transducer positions on the six coated steel panels are shown in Figures 15 through 20. In the left portion of each of the traces is shown the ultrasonic signal received from the panel top surface and the associated multiple thickness back surface signals received. The distance between the top surface signal and the back surface signal is the total panel thickness.

### Conclusions

Based on the brief evaluation performed, it is obvious that there were substantial differences in the oscilloscope traces for the coatings applied over the different surfaces. However, a great deal more work would be necessary to learn how to relate oscilloscope *signals* observed to the differences in coating-metal interfaces. This is an area where more research could result in a new and useful test method.

In each of the chlorinated rubber systems and the epoxy-polyamide systems, the ultrasonic decay or attenuation pattern appears the same for each of the four transducer positions on each panel. This indicates that the coating is fairly uniform over the entire panel.

Observing the attenuation decay pattern, for example, on the chlorinated rubber systems over the clean blasted and rusted steel surfaces, reveals that the latter has a larger signal amplitude and a much longer decay pattern. This same correlation appears to exist for the epoxy-polyamide systems for the clean blasted and rusted steel surface conditions.



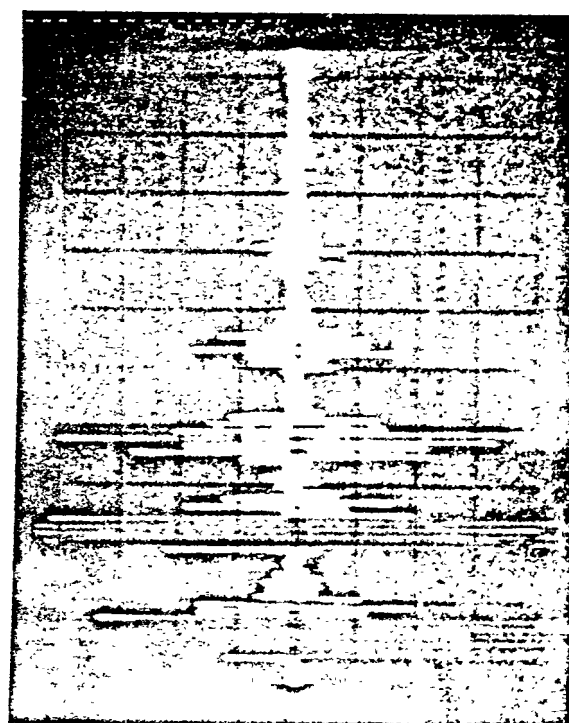
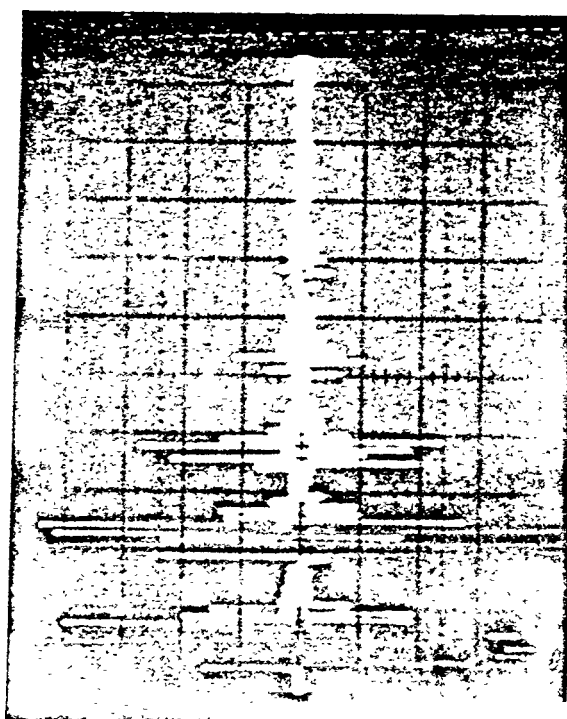
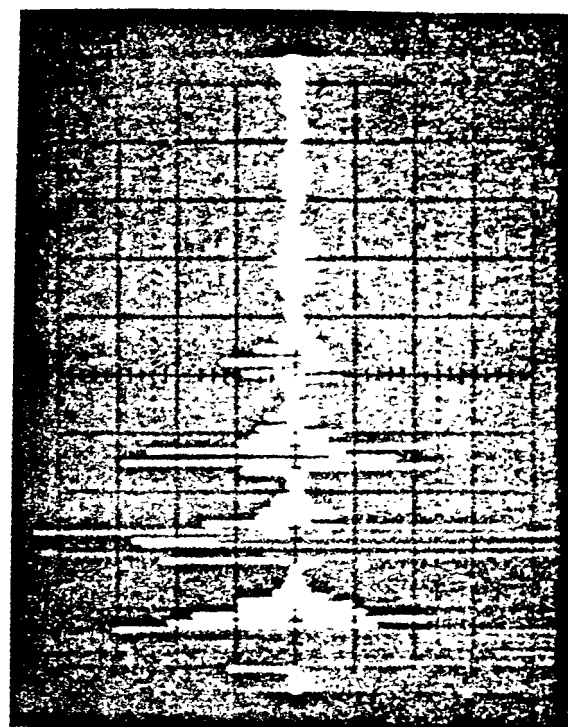
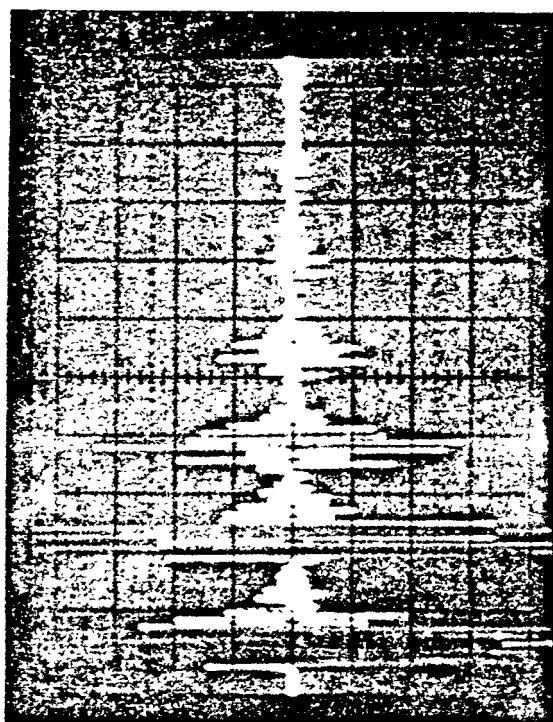


FIGURE 15. OSCILLOSCOPE TRACES FROM PANEL 231 (CHLORINATED RUBBER SYSTEM OVER CLEAN BLASTED SURFACE)

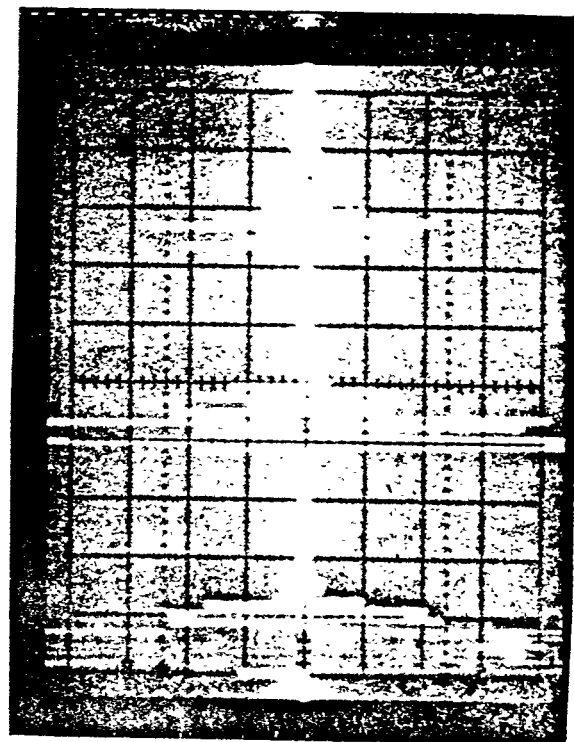
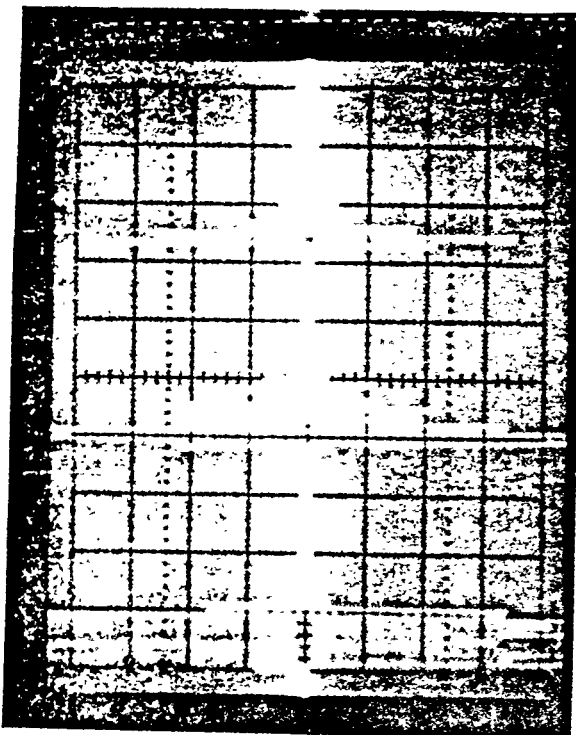
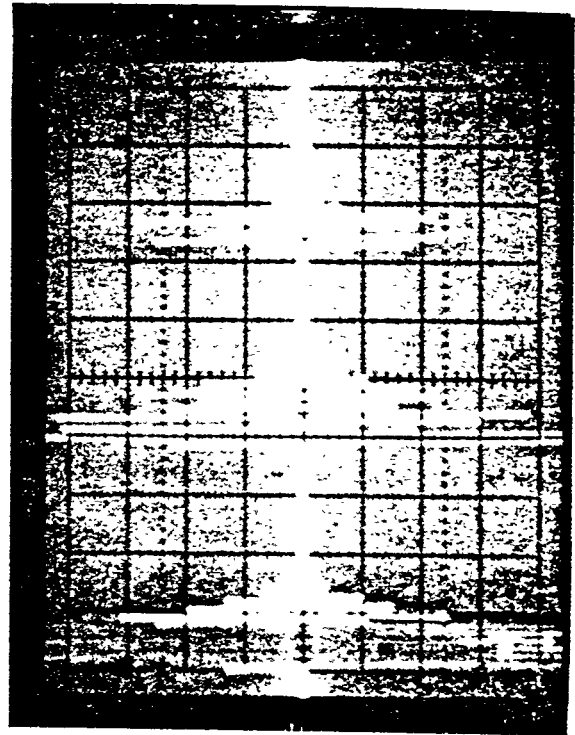
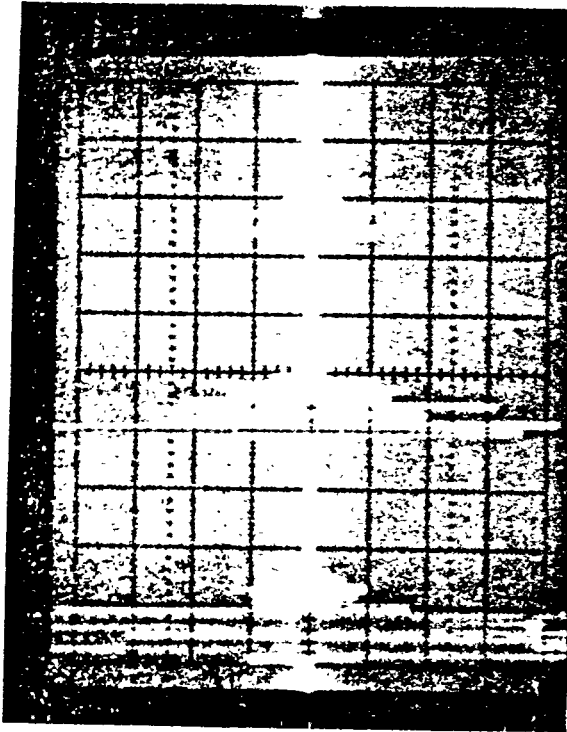


FIGURE 16. OSCILLOSCOPE TRACES FROM PANEL 222 (CHLORINATED RUBBER SYSTEM OVER MILL SCALE)

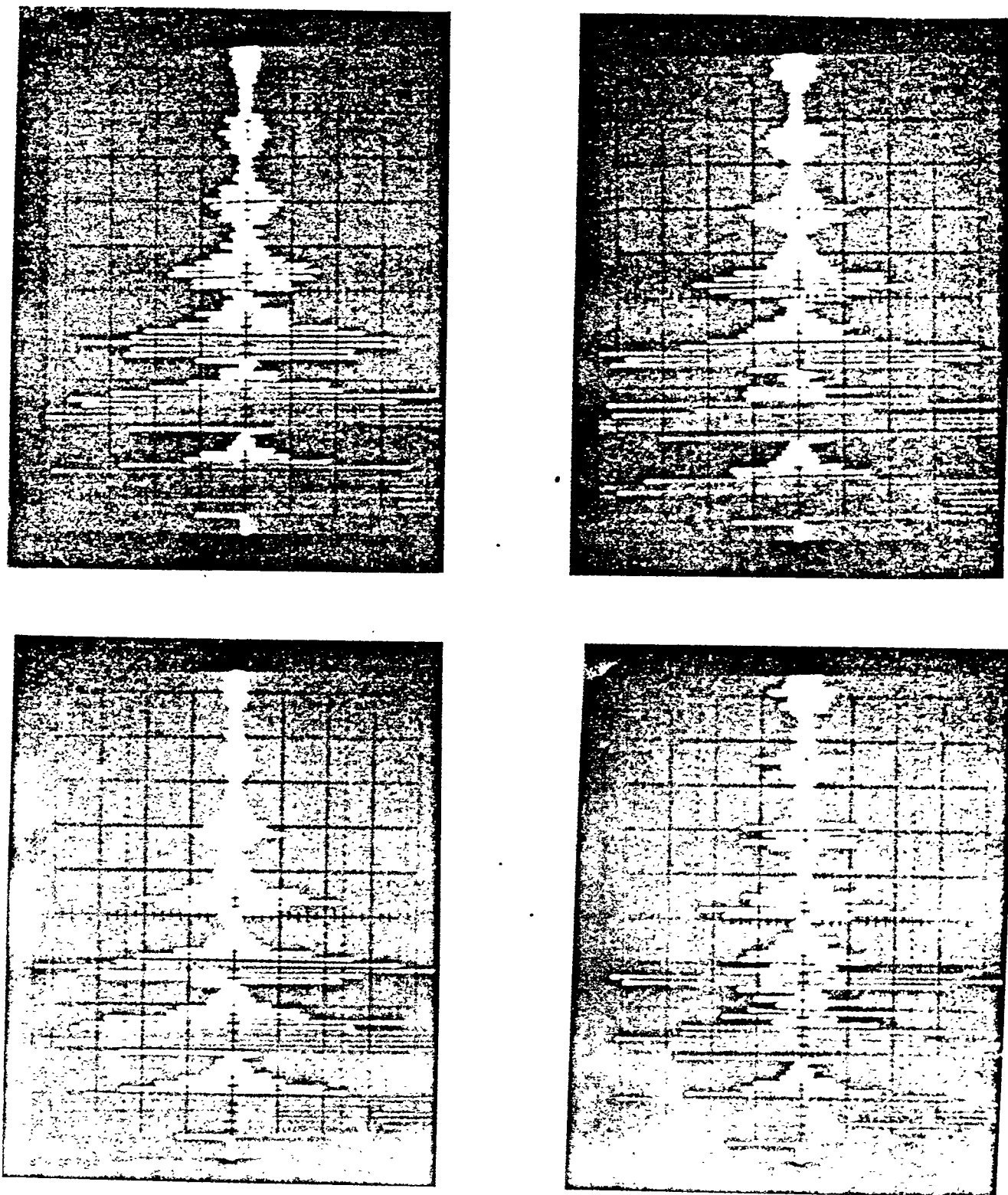


FIGURE 17. OSCILLOSCOPE TRACES FROM PANEL 211 (CHLORINATED RUBBER SYSTEM OVER RUSTED STEEL)

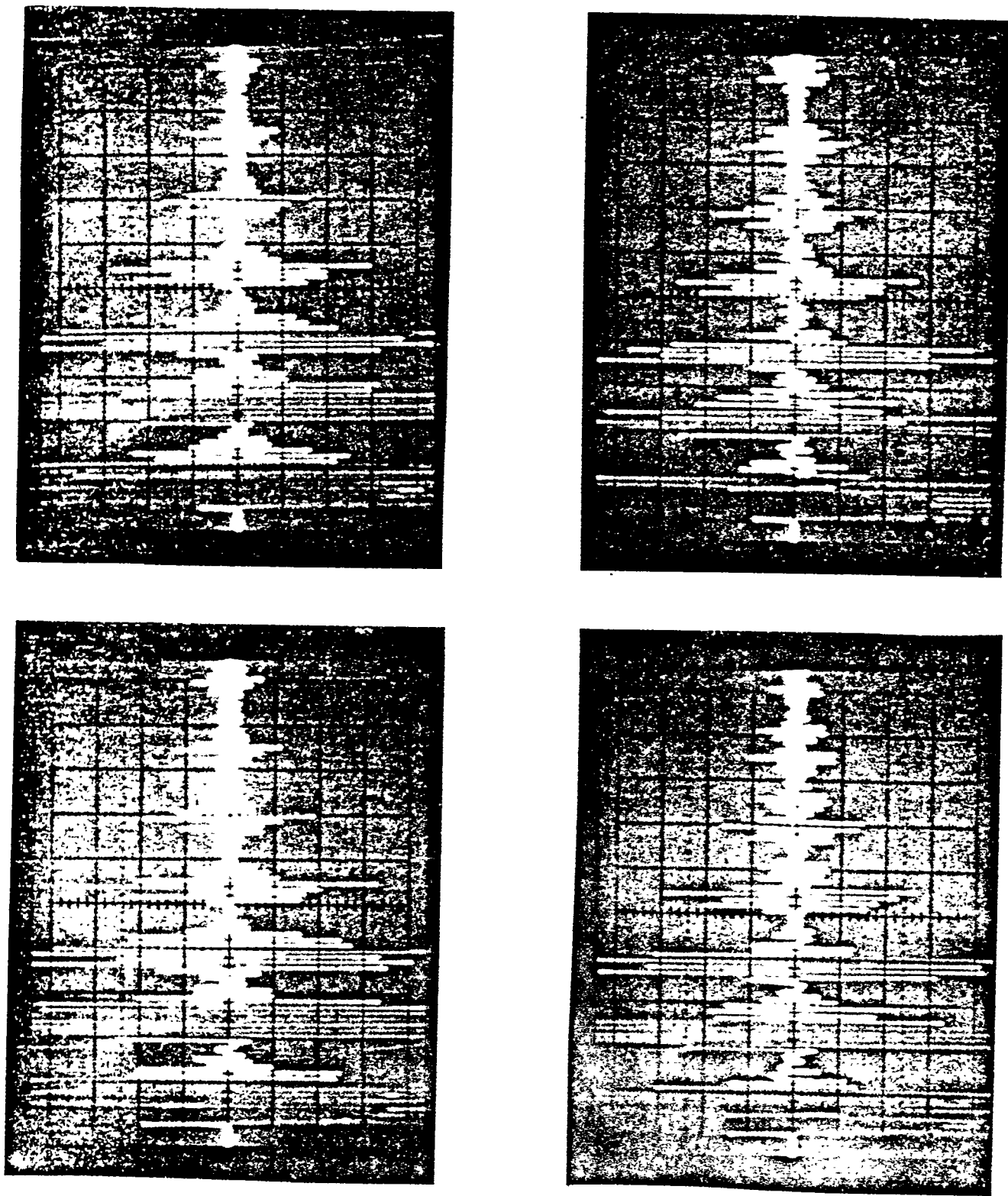


FIGURE 18. OSCILLOSCOPE TRACES FROM PANEL 281 (EPOXY-POLYAMIDE SYSTEM OVER CLEAN BLASTED SURFACE)

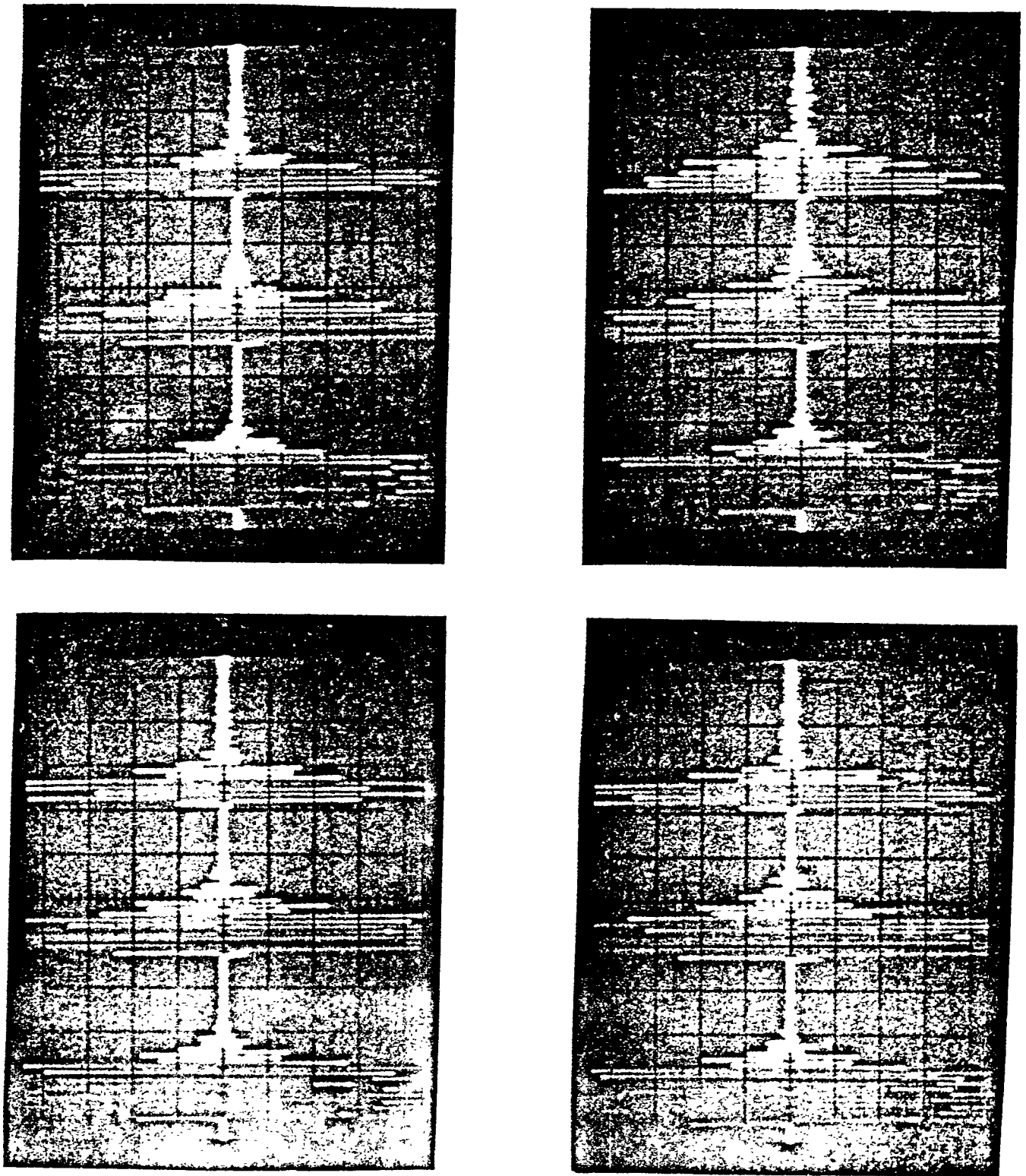


FIGURE 19. OSCILLOSCOPE TRACES FROM PANEL 262 (EPOXY-POLYAMIDE SYSTEM OVER MILL SCALE)

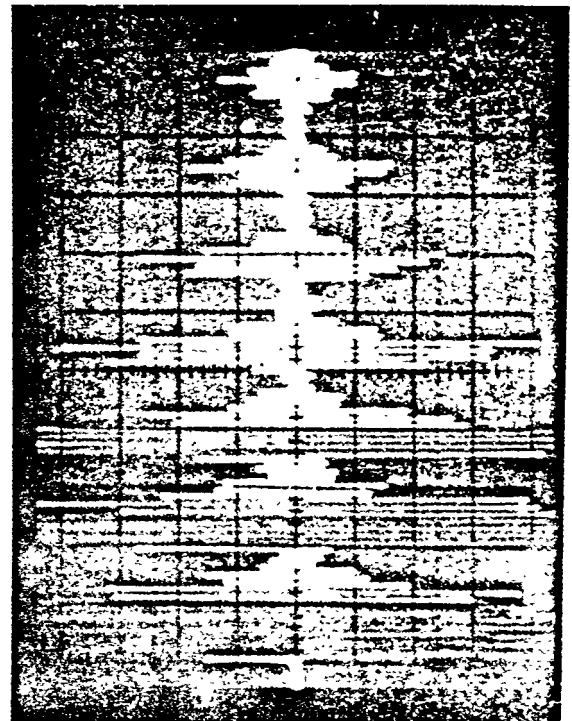
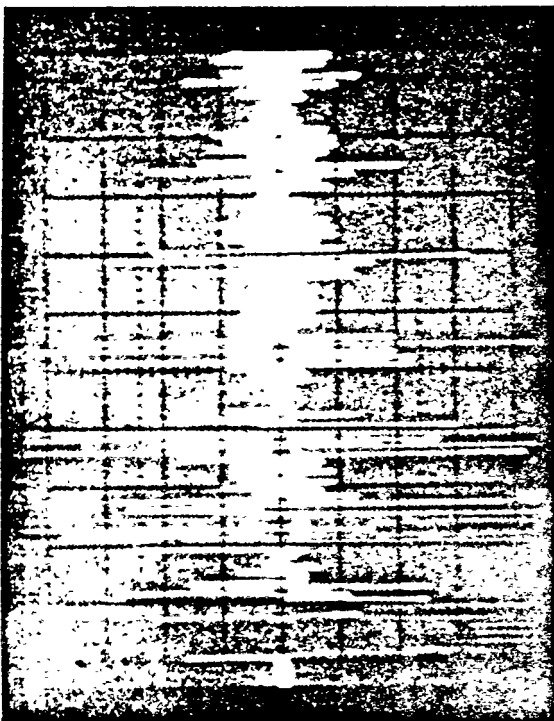
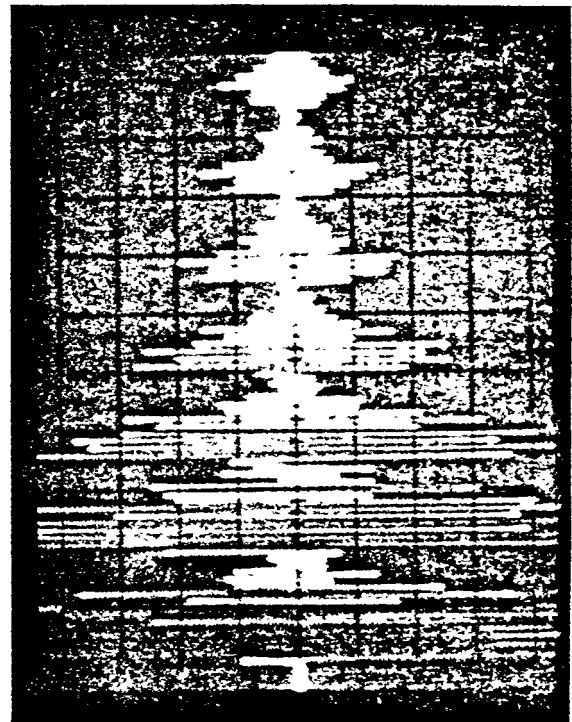
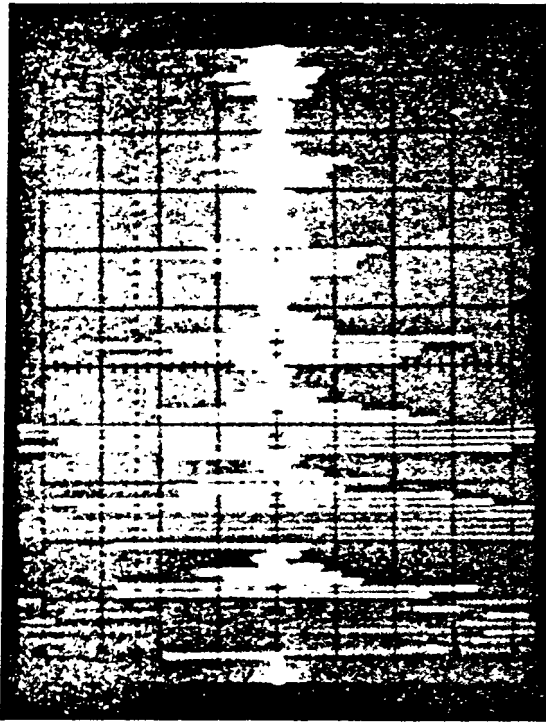


FIGURE 20. OSCILLOSCOPE TRACES FROM PANEL 251 (EPOXY-POLYAMIDE SYSTEM OVER RUST)

PREFAILURE EVALUATION TECHNIQUES  
FOR MARINE COATINGS

SECTION B

## SECTION B

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PREFAILURE EVALUATION TECHNIQUES  
FOR MARINE COATINGS

I INTRODUCTION

Over the years in coating of steels, it has been customary to specify the surface preparation standards by terms such as Blast to White Metal, Blast to Near White Metal or Commercial Blast, etc. In most cases a judgement factor or visual comparison with a standard has been involved. Occasionally the paint crew has been given a wet film thickness to apply but has frequently been given no way, other than judgement, of knowing whether the specified thickness is being applied. Furthermore the desired dry film thickness obtained, while it may meet the specification, may not afford the anticipated or desired protection due to variations in the surface profile. The current investigations-were made to demonstrate the problems, develop relationships between the profile, the-type of paint being applied, the wet thickness, the dry film thickness and the corrosion protection afforded and develop proposed procedures for use in the shipyard.

II OBJECTIVE

The objective of the project was to develop and prove practical shipyard applicable techniques for controlling the blasting and painting operations so that the desired protection of steel would be insured.

III DISCUSSION

Abrasive Blasted Surfaces

The project required the studies to be made on abrasive blasted surfaces. Such surfaces vary according to the size of abrasive used, the speed and duration of blasting and other factors such as distance of nozzle from surface, pressure applied, etc. The results, furthermore, may vary from surface to surface and from operator to operator. Experimental panels of new hot rolled steel, having a Rockwell Hardness between 55 and 75 were furnished by the Shipyard, blasted under uniform conditions to two degrees of blast: (1) a "light blast to clean the surface free of rust and mill scale", considered as "blast to commercial surface", and (2) a "heavy blast", considered as "blast to white surface", where the panels are blasted further than in removing only mill and mill scale. To provide additional test panel material, commercially supplied panels were obtained from the Q-Panel Company as sandblasted panels, Type HRB-36, made from 0.064 hot rolled steel, with a 1 to 2 mil profiles white metal surface. The panels were protected in preservative paper and in plastic bags in a manner to "prevent rust indefinitely".

### Coating the Profile of the Blasted Surfaces

Any application of paint to sand- or grit-blasted surfaces and any thickness measurement on such coated panels is necessarily influenced by the surface condition of the blasted surface. A blasted surface consists of areas where the abrasive has penetrated only lightly into the surface and other areas where it has penetrated more deeply. The distance between the uppermost level of the steel surface and the deepest penetration level can be represented by a line pattern which can be determined by instruments. This is referred to as the "profile" of the steel surface.

The Brush Surface Analyzer, Model BL-103A, was used in this project to study the surfaces of the steel panels, as shown in Figure 1. In order to translate the profile peaks and valleys into units of measurement which would serve to establish the required paint coating thickness to afford the degree of protection desired the instrument was calibrated so that ten horizontal lines in the profile chart represent a difference in surface profile of 1 mil (0.001 inch). In Figure 1, chart a), the surface of one of the panels having a "commercial blasted surface" is shown, that is, a light blast to remove dirt and mill scale. The chart indicates that this panel had an average profile of approximately 1 roil, and maximum profile of 1.4 roils. (In the course of the studies, variations were observed from one panel to another; but generally they remained in this range.)

The profile chart (b) in Figure 1, Shows one of the panels with a "blast to white surface", that is, a heavier blast than in chart (a). The profile variations are around 2.5 mils. Chart (c) in Figure 1 shows the profile chart of one of the Q-Panels, Type HRB-36, where some areas show a 1 mil profile with the highest profile at 2 roils.

### The Coating System

In applying paints to steel surfaces, It is general practice to apply a base material - a primer, to the blasted steel surface. The primer is expected to cover all parts of the profile, the valleys as well as the peaks, and to adhere solidly to the surface, producing a solid bond between the profile of the steel and the subsequent coats.

Measuring the thickness of the coating. and its comparison to the base profile which is being coated, presents problems. The primer applied to the bare steel surface must cover the narrow profile depths as well as the profile peaks. As the charts in Figure 1 show, the lower area of the blasted surface includes wide valleys, where the primer can penetrate and be anchored solidly, and narrow valleys, where coatings of high viscosity and/of a high degree of pigmentation may not penetrate completely and so would not join completely with the substrate. A second difficulty which is faced in such measurements is that most gages work on a magnetic principle. When the heads are wider than the valleys the gages generally measure the paint thickness above the peaks of the profile.

Usually the primers are followed by a paint material which should form a coherent, stable, dry, surface layer strongly adherent to the primer coat. The profile which the top coat must adhere to depends on the degree to which the primer has filled the profile valleys and covered the profile peaks. Figure 2 shows surface analyzer charts of: (1) the profile of the base sandblasted panel, (2) the profile of a panel with a 3 mil coat of inorganic zinc primer, as measured with a MIKROTEST Thickness Gage.

This 3 mil thickness of the primer exceeds the minimum (2 mil) profile of the uncoated panel. The profile of the coated panel has only a 2.4 mil maximum variation. This indicates that the primer coating is thicker in the valleys and thinner on the peaks. The protection afforded by the primer is therefore not uniform over the total surface. If the thickness of coating over the higher peaks is insufficient then added coats of primer must be applied or the top coats which follow must be increased in thickness to achieve the desired system thickness. However increasing the thickness of the top coats to compensate for insufficient primer can change the characteristics and performance of the total system and may therefore not meet the specifications.

Besides these coatings, the underwater area of the ship requires one or more antifouling coats. Anti-fouling coatings are not a part of this study.

Any measurement of the paint thickness using a magnetic type gage over a multiple coat system shows the thickness of all the coats on top of the-blast profile and its peaks. In order to know how much of each separate coat is present, it is necessary to measure individually the thickness of each coat over the preceding coat.

#### Measuring Paint Thickness

paint thickness measurements can be made on the freshly applied - or wet, coating or can be made after the coating has dried, that is, the "dry" film thickness.

The total corrosion protection afforded a coated surface by a specified system is related to the dry film thickness of the coating. Knowing the dry film thickness does not help the painter control his application. He can only measure the wet film thickness. It is therefore necessary to determine the wet film thickness required over a given profile to produce the specified dry film thickness. Coating materials of different formulations and sources give different wet/dry film ratios. This ratio must be established individually for each of the materials.

The wet/dry film relationship has been studied and is reported below.

### IV EXPERIMENTAL WORK

#### Abrasive Blasted Surface

Generally, the blast operator can visually observe how thoroughly the abrasive has removed the rust and mill scale from the surface, such as defined for "commercial blast". Beyond that, he can observe how closely he has approached the state of a "blast to white surface". He may blast beyond that state in certain areas. This possibility has to be considered when setting minimum coating thickness

levels and a margin added. There are no hand operated gages which a blast operator can use for control of the surface. Some efforts to develop a simple instrument have been reported.

Establishing the profile state, measured in mil distance between the highest peaks and the lowest valleys, is not necessarily required in daily operations. However, the profile range which can be expected from a specified blasting process should be determined using laboratory instruments. The profile information which is obtained from these tests can be used to establish the required wet film thickness including margin.

The laboratory instruments used in this step are profilometers, such as the Brush Surface Analyzer. The stylus of the instrument is passed over the test surface in repeated runs one eighth of an inch apart. The trace of the stylus is plotted on chart paper. The chart can be read to obtain: (1) the general roughness of the blasted surface, and (2) the difference between the highest point and the lowest point, and (3) the average roughness.

The profile is defined by the vertical distance between the highest peak and the lowest valley. As an example; between 1.0 mil and 1.4 mil (Shipyard's *Commercial Blast*), or between 2.5 - 3.0 roils (Shipyard's *Heavier Blast*), or between 1-2 roils (for the Q-Panels, Type HRB). To get complete coverage of a surface to obtain the full protection of the paint system, it is necessary to base the required minimum coating thickness on the highest profile points on the blasted surface. Otherwise, such high points act as starting points for moisture penetration and paint failure.

Some profilometer laboratory instruments do not give the actual high and low points, but give an instrumentally averaged curve. This type of instrument is unsatisfactory for establishing the required coating thickness.

The fact that the unprotected, individual, high peaks represent exposed points for subsequent failure is shown by the electrographic prints. The unprotected peaks appear as black spots. For example, Figure 3 shows prints of one of the Shipyard's "commercial blast" panels, where a 1-1.4 mil profile has been coated with three equal coats of 1.5 mil dry film thickness. The prints show that upon saltfog exposure, during the first 100 hours no, or very few, unprotected peaks appear. After 250 hours exposure, moisture begins to spread from the test cross into the paint layers, and corrosion spots appear. These are not caused by initially uncovered peaks but moisture penetration from the test cross into layers of different coats. In Figure 4 prints are shown where a 9 mil coating system has been applied and after 250 hours saltfog exposure, no unprotected areas are evident.

The results of saltfog exposure tests on a 1 mil coating are also shown in Figures 3 and 4. The unprotected peaks create failure points which become progressively worse with increased exposure.

In Figure 5 only .0.8 mil paint has been applied. The failure spots appear earlier in the saltfog exposure period over the whole blast area. The lesser density of the spots in the print where a 1 mil coating was present, also indicates that more of the lower peaks had been protected with the 1 mil thick coating than with the 0.8 mil coating.

Specifying the required dry film thickness must be based on protection of the highest peaks on the blasted surface.

### Coating the Profile of the Blasted Surfaces

Examination of the profile charts of figure 1 shows that there are two painting problems: (1) covering the peaks and (2) covering the valleys.

The paint must have a solids content high enough to develop the dry film thickness required over the peaks and the viscosity must be low enough to penetrate to the narrow bottoms of the valleys. Covering of the peaks has been discussed previously. If the paint does not penetrate to the bottom of the valleys and adhere properly to the base metal it will form bridges. Beneath these bridges, there will be uncoated, and unprotected voids. Adherence of the coating system will be impaired.

The primers used in the present project were of the inorganic zinc type. The program did not include studies to determine whether all valleys of the blast profile were completely coated.

### Methods of Measuring Coating Thickness

#### Measuring the Wet Film Thickness

Gages for measuring wet film penetrate the coating with a measuring pointer (as with the ELCOMETER or NORDSON Wet Film Thickness Gage) or a scratch (as with the Interchemical Wet Film Thickness Gage). This disfigures and punctures the coating and these defects remain in the coating after the paint dries. The operator should give these "gage mark areas" a slight overspraying to repair the coating.

A wet film contains essentially all of the initial content of volatile matter of the paint material. With the progressive drying, this volatile matter evaporates and the film becomes "less wet" and its thickness will decrease until it reaches the dry film thickness. This varies with each coating material. For each material the wet film/dry film ratio must be determined so the operator can be instructed as to the wet film thickness to apply to obtain the required dry film thickness. An example of this is given in Tables 1 to 4-A, showing the changes from the applied wet film thickness to the resulting dry film thickness: In Table 1 for an inorganic zinc primer; in Table 2, for an epoxy polyamide middle coat; in Table 3 for a modified acrylic top coat. In Table 4 these data are used to obtain the dry film thickness specified. Table 4-A shows what can happen if it is assumed that the wet/dry film ratio is the same for the three different paints in the coating system. This clearly demonstrates the need to determine the individual wet/dry film ratio for each product.

Wet film thickness should be measured at approximately the same time after paint application. Table 5 shows the variation of wet paint film thickness against time after application. It can be noted that there is a time period during which the variation is small. This is the time when the freshly applied film has "settled" enough to allow the entrapped air and (highly) volatile solvents

to escape before the film has dried enough to approach a dry film condition. During this interval the wet film readings are consistent and useful for control purposes. In painting vertical or inclined surfaces, the sagging of the freshly applied paint must also be considered. Sagging from vertical and inclined surfaces will cause variations in dry film thickness even though identical wet films have been applied. The extent of sagging will vary for different paint materials, for different wet film applications, and even for different temperature conditions during the drying.

#### Measuring the Dry Film Thickness

The dry film must resist the requirements of exposure, of mechanical attack, and of aging. Therefore, the dry film thickness reading is essential. The thickness of the required final dry coating must be determined in relation to the blast profile.

Some years ago the Committee on Surface Preparation of the National Association of Corrosion Engineers and others recommended, for "commercial blast" profiles, the dry film thickness should be equal to about five times the distance between the highest peaks and the lowest valleys. This "rule of Thumb" has been reasonably substantiated by the project tests.

The blasting operator will not have continuous measurements of profile being obtained. The profile will vary. To insure minimum required dry film thickness on the variable profile, a small factor of safety should be included in the specified wet film thickness.

With the heavier profile "blast to white surfaces", the profile was found to be 2.5 to 3 roils. According to the exposure tests, the total dry film thickness should be, at least three times the greatest profile depth, or - to allow for possible variations - somewhat more.

There are a great many dry film thickness gages available, and many of them were tested during this project. They gave quite uniform readings. All gages operating on a magnetic principle express the coating thickness above the general magnetic base level and not above the blast cavities, or valleys. On thin coating applications, some gages with small sensing heads may be influenced by the position of the head-over high peaks or deep valleys. Gages with wide sensing heads when used over heavier coatings, usually avoid this problem.

Readings taken with laboratory model COATINGAGE (Branson Instruments, Inc., Stamford, Conn.) and the MAGNE-GAGE (American Instrument Company, Silver Spring, Md) were compared with readings taken with several hand-operated gages, such as might be used by painting crew or inspector. Correlation was good.

Although there are hand-operated dry film gages available which puncture the coating, none of this type was tested. The magnetic types that were used or tested during the project were:

- (1) Elcometer
- (2) Mikrotest
- (3) Gardner - Inspector

A list of the gages used during this program is in Table 6.

V RECOMMENDED SURFACE PREPARATION AND COATING PROCEDURE

1. The steel surface is cleaned to a degree specified by the Engineering Department.
2. The blaster checks the profile by a Keane-Tator Surface Profile Comparator.
3. The laboratory checks the profile by a profilometer once a week.
4. The laboratory analyzes the size of the abrasive once a week and recommends the abrasive composition.
5. The Engineering Department specifies the coating system, the number of coats, the wet and the dry film thickness.
6. The Quality Control Department checks:
  - 6.1 The blasted surface before releasing it for painting for degree of cleanliness by comparison with the Steel Structures Painting Council standards or the Swedish Surface Preparation Standards.
  - 6.2 If the surface is free of moisture.
7. The spray painter applies one coat of paint and measures the wet film thickness during the application. After each measurement he sprays over the marks left by the wet film gage.
8. After one coat is dry or cured the dry film thickness is measured by the foreman before release to apply the next coat.
9. Procedure 7 and 8 are repeated during - or after application of each coat.
10. Finally the total dry film thickness is measured by the Quality Control Department and a statement for the owner is issued stating that the whole coating system was applied according to the manufacturer's instructions and to the Painting Specification issued by the Engineering Department.



Chart a): THE SHIPYARD'S PANEL WITH THE "COMMERCIAL BLAST" TO REMOVE DIRT AND MILL SCALE. AVERAGE PROFILE: 1 MIL. MAXIMUM AREAS: 1.4 MILS

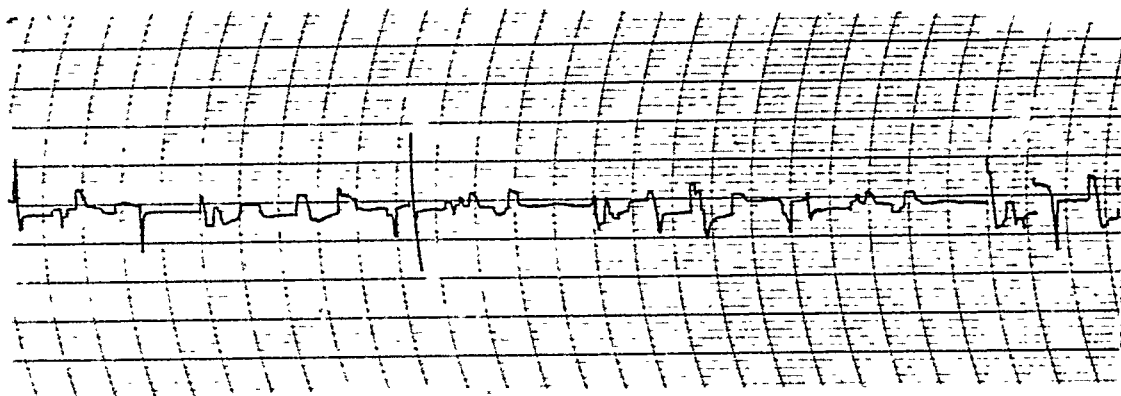


Chart b): THE SHIPYARD'S PANEL WITH "BLAST TO NEAR WHITE SURFACE" OR "HEAVIER BLAST". MAXIMUM PROFILE: 2.5 MILS (AND SLIGHTLY ABOVE)

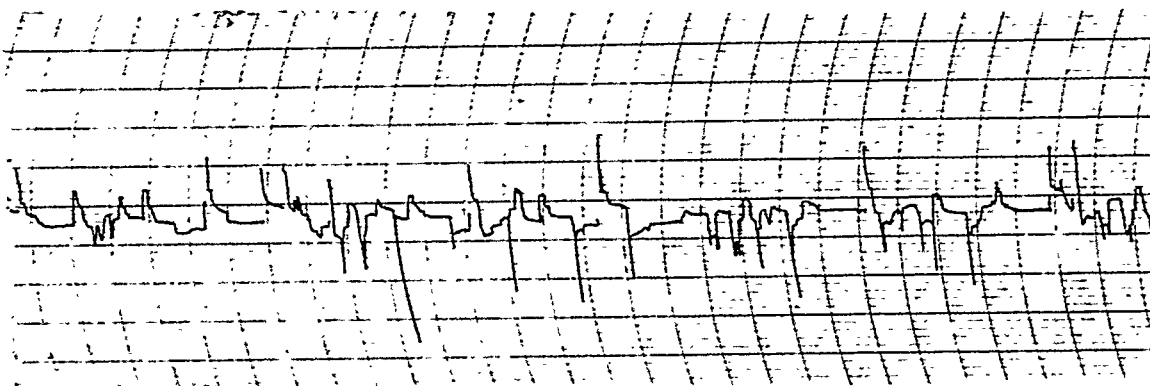


Chart c): THE Q-PANEL, TYPE HRB-36,  
HIGHEST PROFILE; 2 MILS; OTHER AREAS ABOUT 1 MIL.

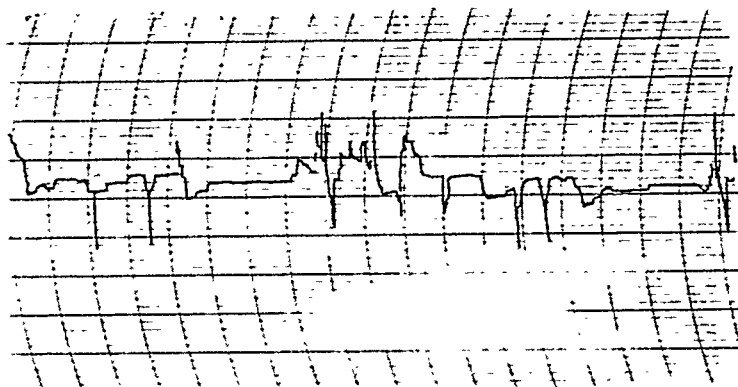


FIGURE 1 THE PROFILES OF THE THREE TYPES OF TEST PANELS USED IN THESE STUDIES  
(BRUSH SURFACE ANALYZER CALIBRATED TO 10 HORIZONTAL LINES PER 1 MIL)

Chart a): PROFILE OF THE UNPAINTED PANEL:  
 MAXIMUM DIFFERENCE BETWEEN THE HIGHEST AND LOWEST POINTS ON THE  
 SURFACE IS 20 HORIZONTAL LINES, OR 2 MILS.



Chart b): PROFILE AFTER APPLICATION OF THE PRIMER:  
 DRY FILM THICKNESS (MIKROTEST): . . . . . 3.0 MILS  
 REMAINING PROFILE DEPTH ABOVE THE DRY PRIMER SURFACE: ABOUT 0.4 MILS

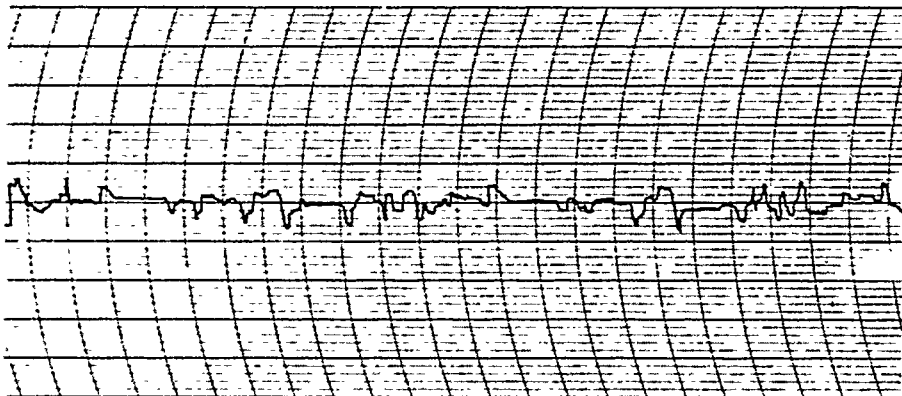


CHART NO. RA-2911-30

FIGURE 2 APPLICATION OF THE INORGANIC ZINC PRIMER TO SANDBLASTED Q-PANEL  
 (BRUSH SURFACE ANALYZER CALIBRATED TO 10 HORIZONTAL LINES PER 1 MIL)

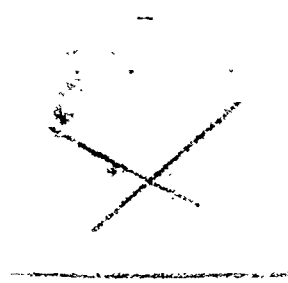
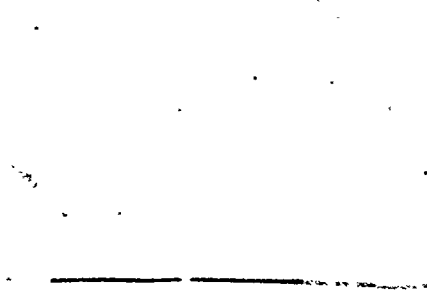
THREE COATS OF 1.5 MILS EACH  
TOTAL: 4.5 MILS COATED BY  
OTHERS

TWO COATS OF MODIFIED ACRYLIC  
TOTAL: 6 MILS ON  
BARE BLASTED SURFACE.  
COATED BY US

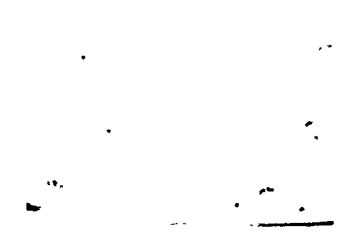
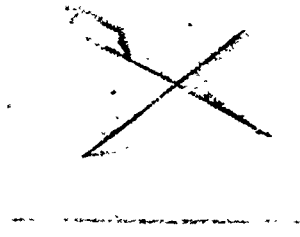
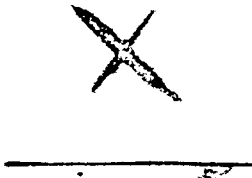
TWO COATS OF MODIFIED  
ACRYLIC. THINNED  
2:1. TOTAL: 1 MIL  
COATED BY US.

HOURS  
SALT-  
FOG

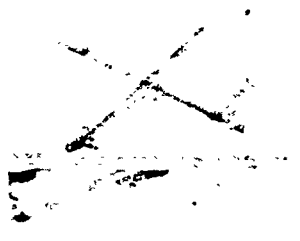
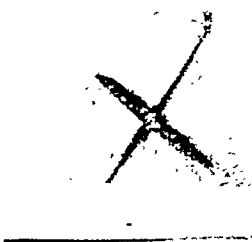
0



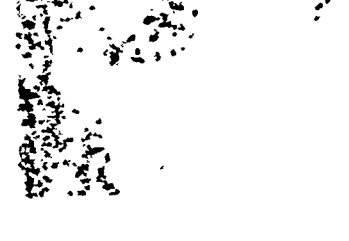
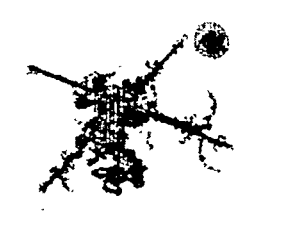
100



250

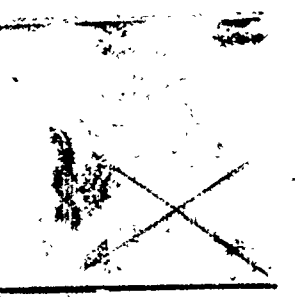


500



WITH ADDITIONAL COAT  
OF MODIFIED ACRYLIC

650



775

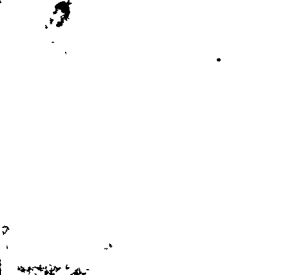
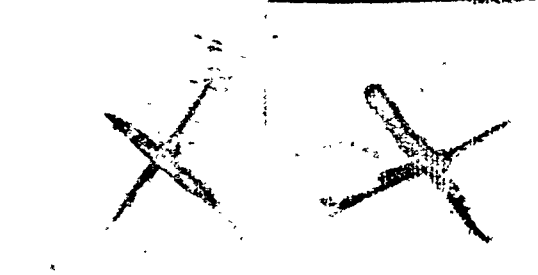


FIGURE 3 ELECTROGRAPHIC PRINTS OF PANEL I COMMERCIAL BLAST

WHITE SURFACE  
PAINT FILM:  
4.5 MILS COATED  
BY OTHERS

WHITE SURFACE, TWO COATS  
OF MODIFIED ACRYLIC.  
TOTAL: 5.5 MILS COATED  
BY US

ONE COAT OF MODIFIED ACRYLIC  
DILUTED. PAINT 0.8 MIL COATED  
BY US

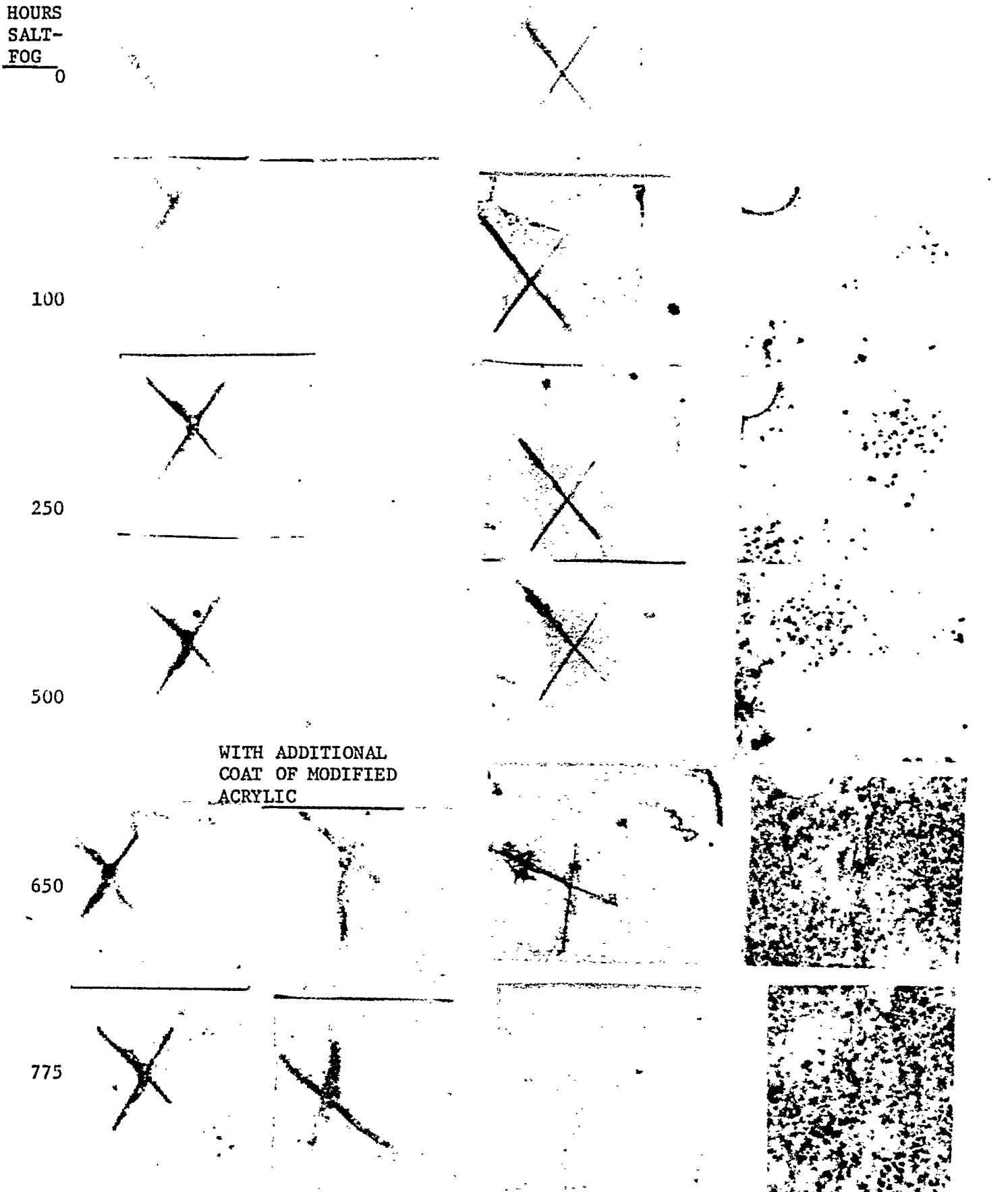


FIGURE 5 ELECTROGRAPHIC PRINTS OF PANEL III BLAST-TO-WHITE SURFACE

COMMERCIAL BLAST PAINT  
9 MILS. COATED BY OTHERS

TWO COATS OF MODIFIED ACRYLIC.  
TOTAL: 8 MILS. COATED BY US

ONE COAT OF MODIFIED  
ACRYLIC. DILUTED 2:1  
FILM:1 MIL. COATED BY US

HOURS  
SALT-  
FOG

0

100

250

500

650

775

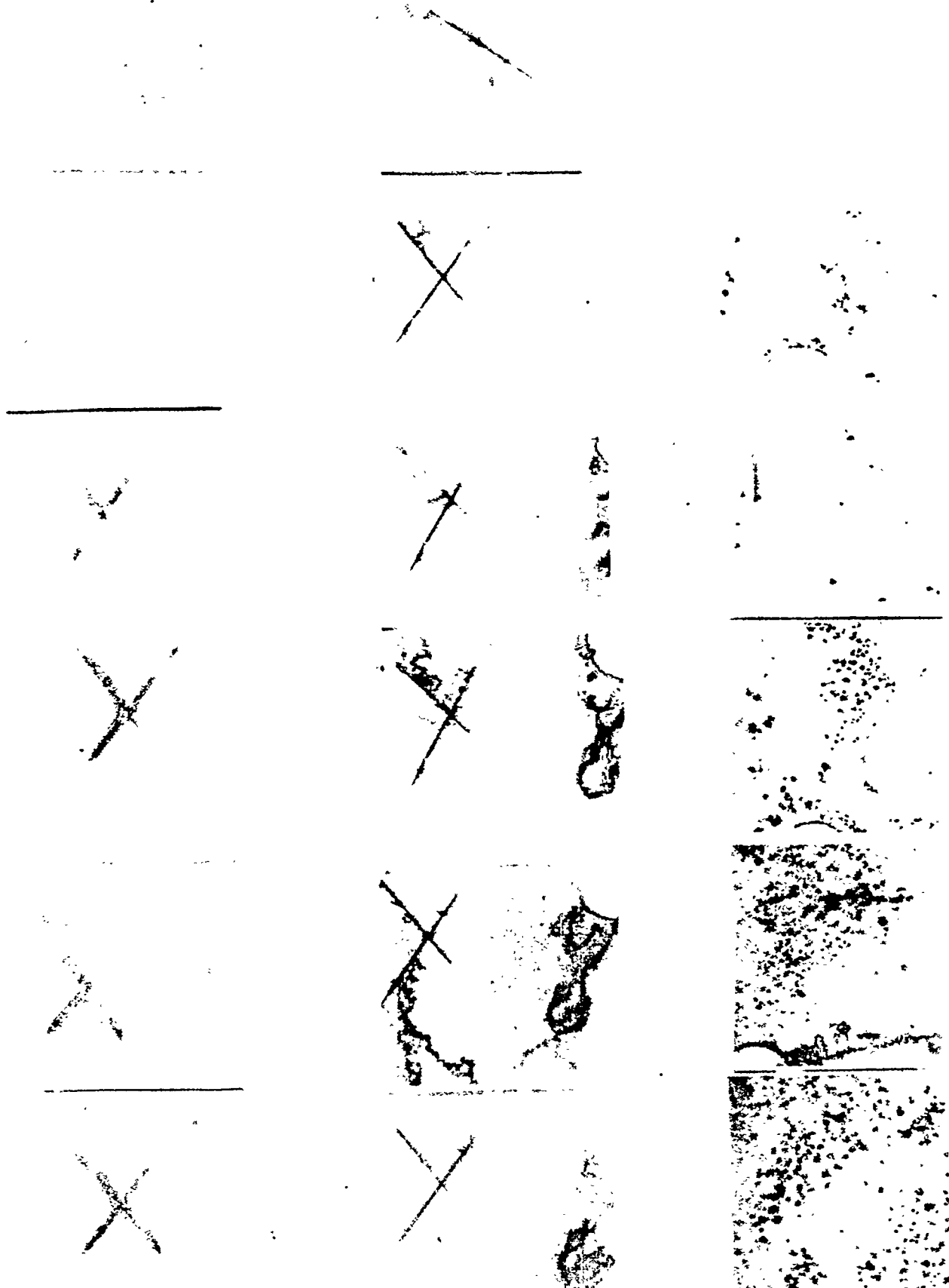


FIGURE 4 ELECTROGRAPHIC PRINTS OF PANEL II

TABLE 1

## THE RELATIONSHIP BETWEEN WET FILM APPLICATIONS AND THE RESULTING DRY FILM THICKNESS

Studies with inorganic zinc primer:

Panels used: Sand blasted hot rolled steel panels (Type HRB-36, The Q-Panel Co.), or Cold rolled smooth panels (Type R-36, The Q-Panel Co.).

The panels were placed on the magnetic plate of a permanent magnet chuck to assure a stable position of the panel to be coated.

The paints were applied with standard film applicators: Either the Bird Film Applicator with wet film standard thickness of 3 mils or of 6 mils, or the Adjustable Boston-Bradley film applicator (Gardner Catalog B6-5 No. AG 3830).

Within 1 hour after primer application, a slight water spray was applied, in accordance with the instructions of the manufacturer.

First Test Group:

<u>Panel Type</u>	<u>Applicator Used</u>	<u>Wet Film Thickness</u>	<u>Dry Film Thickness</u>
Smooth	Bird	6.0 mils	3.5 mils
Smooth	Boston-Bradley	8.0 mils	3.6 mils
Sand Blasted	Bird	6.0 mils	3.25 mils
Sand Blasted	Bird	6.0 mils	3.5 mils
Sand Blasted	Boston-Bradley	8.0 mils	4.2 mils
	TOTAL	34.0 mils	18.05 mils
	PER	100 mils	50.00 mils

Second Test Group:

Smooth	Panel No. 2	6.0 mils	3.0 mils
Smooth	Panel No. 3	6.0 mils	2.6 mils
Smooth	Panel No. 4	6.0 mils	2.5 mils
Smooth	Panel No. 5	6.0 mils	2.7 mils
Sand Blasted	Panel No. 6	6.0 mils	2.5 mils
Sand Blasted	Panel No. 7	6.0 mils	2.7 mils
Sand Blasted	Panel No. 8	6.0 mils	2.5 mils
Sand Blasted	Panel No. 9	6.0 mils	2.8 mils
Sand Blasted	Panel No. 10	6.0 mils	2.7 mils
	TOTAL	54 mils	24.0 mils
	PER	100 mils	44.4 mils

Summary:

Average in First Test Group: Per 100 mils wet film . . . . 50 mils dry film  
 Average in Second Group: Per 100 mils wet film . . . . 44.4 mils dry film.  
 Average of 14 applications: Per 100 mils wet film . . . . 47 mils dry film.

TABLE 2

## APPLICATION OF THE WET FILM/DRY FILM MEASUREMENTS TO THE MIDDLE COAT

Middle coat applied: The epoxy polyamide.

Primer coat: As shown in Table 1, Second Test Group.

<u>PANEL</u> <u>*NUMBER</u>	<u>UNDERCOAT</u> <u>DRY FILM</u> <u>THICKNESS</u>	<u>MIDDLE COAT</u> <u>WET FILM</u> <u>THICKNESS APPLIED</u>	<u>TOTAL DRY FILM THICKNESS</u> <u>ELCOMETER</u>	<u>BRANSON</u>	<u>AVERAGE</u>	<u>DRY FILM</u> <u>THICKNESS OF</u> <u>MIDDLE COAT</u>
3	2.6 mils	6 mils	5.0 mils	5.3 mils	5.15 mils	2.55 mils
4	2.5 mils	6 mils	5.0 mils	5.3 mils	5.15 mils	2.65 mils
5	2.7 mils	6 mils	5.0 mils	5.0 mils	5.0 mils	2.70 mils
7	2.7 mils	6 mils	5.0 mils	5.0 mils	5.0 mils	2.70 mils
8	2.5 mils	6 mils	5.0 mils	5.0 mils	5.0 mils	2.50 mils
9	2.8 mils	6 mils	5.5 mils	5.7 mils	5.6 mils	2.80 mils
10	2.7 mils	6 mils	5.5 mils	5.3 mils	5.4 mils	2.70 mils
TOTAL		42 mils				18.60 mils
PER		100 mils wet film . . . . .				40.4 mils drv
OR PER		10 mils wet film . . . . .				4 mils dry

\*Foot Note: The panel numbers refer to the same panels as in Table 1.

TABLE 3

## APPLICATION OF THE WET FILM/DRY FILM MEASUREMENTS TO THE TOP COAT

Top Coat Applied: Modified Acrylic, using film applicator: The wet film thickness was measured immediately after coating the panel, using Nordson Gage.

Primer Coat: Inorganic zinc primer

Middle Coat: Epoxy polyamide

The dry film thickness of the preparatory coatings was determined with the Coatingage of Branson Instruments, Inc; the total dry film thickness on the panels was measured with the Coatingage.

<u>PANEL *NUMBER</u>	<u>UNDERCOATS DRY FILM THICKNESS</u>	<u>TOP COAT WET FILM THICKNESS</u>	<u>DRY FILM THICKNESS OF ALL COATS</u>	<u>TOP COAT DRY FILM THICKNESS (CALCULATED)</u>
1	3.5 mils	8 - 10 mils	6.5 mils	3.0 mils
2	1.8 mils	7 - 8 mils	4.5 mils	2.7 mils
4	7.0 mils	5 - 6 mils	9 mils	2 mils
5	5.5 mils	12- 16 mils	10 mils	4.5 mils
6	8.0 mils	10 mils	12 mils	4 mils
7	5.5 mils	6 mils	7.5 mils	2.0 mils
9	6.0 mils	6 mils	8 mils	2 mils
10	5.0 mils	6 mils	7 mils	2 mils
	<u>TOTAL:</u>	<u>60 - 68 mils</u>		<u>22.2 mils</u>
	PER	100 mils . . . . .		32.6 - 37 mils or 35 mils average.

\*Foot Note: The panels were freshly prepared with primer and middle coat for these top coat tests.



TABLE 4

CALCULATING FROM THE RESULTS OF TABLES 1, 2, AND 3 THE REQUIRED WET FILM THICKNESS FOR EACH OF THE PAINTS TO OBTAIN 1 MIL DRY FILM

Primer: Average findings in 14 applications (With reference to Table 1):  
 100 mils wet film gave 47 mils dry film.  
 2.13 mils wet film application will give 1 mil dry paint.

Middle Coat: Epoxy polyamide (with reference to Table 2):  
 100 mils wet film gave 40.4 mils dry film.  
 2.475 mils wet film application will give 1 mil dry paint.

Top Coat: Modified acrylic coating (with reference to Table 3):  
 100 mils wet film gave 35 mils dry film.  
 2.86 mils wet film application will give 1 mil dry paint.

Therefore: To obtain the film thickness which had been specified by the Shipyard the paints would have to be applied in thickness as indicated below:

PAINT APPLIED	FOR LIGHT COAT APPLICATION		FOR HEAVY COAT APPLICATION	
	WET COAT THICKNESS	DRY COAT THICKNESS	WET COAT THICKNESS	DRY COAT THICKNESS
Primer Coat	3.2 mils	→ 1.5 mils	6.4 mils	→ 3 mils
Middle Coat	3.71 mils	→ 1.5 mils	7.425 mils	→ 3 mils
Top Coat	4.29 mils	→ 1.5 mils	8.58 mils	→ 3 mils
	11.2 mils	→ 4.5 mils	22.4 mils	→ 9 mils total thickness

TABLE 4-A

CALCULATING THE EFFECT OF NOT DIFFERENTIATING THE WET/DRY FILM RATIO OF  
THE THREE DIFFERENT PAINTS

It has been established for the primers

3.2 roils wet gives 1.5 mil dry and 6.4 roils wet gives 3 roils dry.

If the same wet film thickness were to be applied of the middle and top coats,  
the results would be:

For Middle Coat:	3.2 roils wet would give	<b>1.29 mils dry &amp; 6.4 mils wet</b>	<b>→ 2.58 mils dry</b>
	instead of required	1.5 roils dry &	3 roils dry.

For The Top Coat:	3.2 roils wet would give	<b>1.07 mils dry &amp; 6.4 mils wet</b>	<b>→ 2.14 mils dry</b>
	instead of required:	<b>1.5 mils dry &amp;</b>	3 roils dry.

The total dry film thickness would then be:	3.86 roils	and	7.72 mils
	instead of required: 4.5 roils	and	9 roils.

TABLE 5

## THE FACTOR OF DRYING TIME IN TAKING THE WET FILM THICKNESS MEASUREMENTS

a) Panels used: Cold rolled steel Q-Panels, at room temperature.

Test Paint used: Modified acrylic coating (Undiluted)

Gage used: Nordson wet film gage.

<u>TEST I</u>		<u>TEST II</u>		<u>TEST III (A THINNER COAT)</u>	
THICKNESS		THICKNESS		THICKNESS	
MEASUREMENTS TAKEN		MEASUREMENTS TAKEN		MEASUREMENTS TAKEN	
EVERY 15 SECONDS		EVERY 30 SECONDS		EVERY 30 SECONDS	
TEST TIME	(MILS)	TEST TIME	(MILS)	TEST TIME	(MILS)
0:00	7 - 8	0:00	8 - 10	0:00	7
15 SEC.	7 - 8	30 SEC.	6 - 7	0:30 SEC.	6 - 7
30	6 - 7	1:00 MIN.	6 - 7	1:00 MIN.	5 - 6
45	6 - 7	1:30	6 - 7		
1:00 MIN.	6 - 7	2:00	6 - 7		
1:15	6 - 7	2:30	5 - 6		
1:30	6 - 7	3:00	5 - 6		
1:45	6 - 7	3:30	4 - 5		
2:00	6 - 7	4:00	4 - 5		
2:15	6 - 7	4:30	TOO STICKY		
2:30	6 - 7		TO READ.		
2:45	6 - 7				
3:00	5 - 6				
4:00	4 - 5				
5:00	4 - 5				

NOTE: Since the paint had been brushed on, the first time interval measurements might be influenced by the flowing out of brush marks. Subsequent changes in wet film thickness are caused by solvent evaporation and continued drying.

b) Thickness measurements made on application of the middle coat paint (epoxy polyamide).

<u>TIME</u>	<u>THICKNESS</u>
	(MILS)
0:00	16
5:00 MINUTES	12
12:00 MINUTES	12
45:00 MINUTES	7

TABLE 6

## GAGES USED IN THE WORK OF THE PROJECT

## I. SURFACE PROFILE METER

Brush Surface Analyzer, Model BL-103A	The Brush Development Company Cleveland, Ohio
---------------------------------------	--

A laboratory instrument providing permanent charts of the surface.

## II. THE FILM APPLICATORS

- |  |  |
|--|--|
| a) Bird Film Applicator, with wet film standard thickness of 3 roils or 6 roils. (Available in other thicknesses also) | Gardner Laboratory, Inc.<br>Catalog B/6-2 #AR-3800<br>Bethesda, Maryland 20014 |
| b) Adjustable Boston-Bradley Film Applicator   | Gardner Catalog B/6-5 AG3830   |

## III. PANEL HOLDER

Permanent magnet chuck with regular pole spacing	Brown & Sharpe Mfg. Company North Kingston, Rhode Island 0285 Catalog STM-2: Shop Tool Manual #745 -510-1
--	--

A laboratory instrument to hold panels solidly during paint application.

## IV. WET FILM GAGES

- |  |  |
|--|--|
| a) Interchemical (Inmont) wet film thickness gage  | Gardner Catalog B/9-1 CG-6280  |
| Well reading, but leaves a scratch line in the surface which can contribute to under film spreading. |  |
| b) Nordson wet film gage 0-20 mil range  | Nordson Corporation<br>652 Rahway Avenue<br>Union, New Jersey 07083<br>Part Number 790 010 |
| c) Elcometer wet film thickness gage stainless steel   | Gardner Catalog B/9-3 GR-6300  |
| d) Elcometer wet film thickness gage plastic, discardable  | Gardner Catalog B/9-3 GR-6300  |

Gages b) - d) leave in the paint film impressions which remain in the drying film and appear, upon saltfog exposure, in the electrographic prints.

It is recommended to shortly overspray fresh surfaces after the wet film measurements have been taken, in order to restore the coating surface.

TABLE 6 (Cont'd)

## v. DRY FILM GAGES

## A. Laboratory Models

- a) Magne-Gage, with magnets and thickness standards      American Instrument Company  
Silver Spring, Maryland 20907  
Catalog Number 5-660.

Depends on the attraction of a thin magnet to the dry coated steel surface. Might be influenced by the broken surface of the grit blast steel.

- b) Coatingage, Model 600      Branson Instruments, Inc.  
Stamford, Connecticut 06904

Battery operated. Works well, but it must be given attention to the condition of the batteries.

## B. Hand Operated Models

- a) Gardner Needle Thickness Gage      Gardner Laboratory, Inc.  
Bethesda, Maryland 20014  
Catalog Number B/9-4 GG-6288

Presses a needle into the film to give close contact with the metal substrate. Requires some care in operation, but gives accurate readings.

- b) Elcometer Thickness Gage, Type A      Gardner Catalog Number GR-6270

- c) Mikrotest Thickness Gage, Model      DeFelsko. Corporation  
F I M for coating thickness      Ogdensburg, New York 13669  
range 1/2 thou" to 20 thou".  
Test set model F standards, 0  
to approx. .02".

Reads dry film thicknesses between 0.5 mil and 20 mils.

- d) Inspector Thickness Gage      Gardner Catalog B/9-10 GR-6350

Similar to c).

